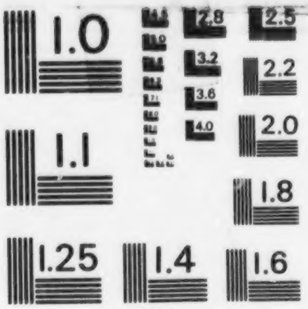
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Streambank Protection Guidelines

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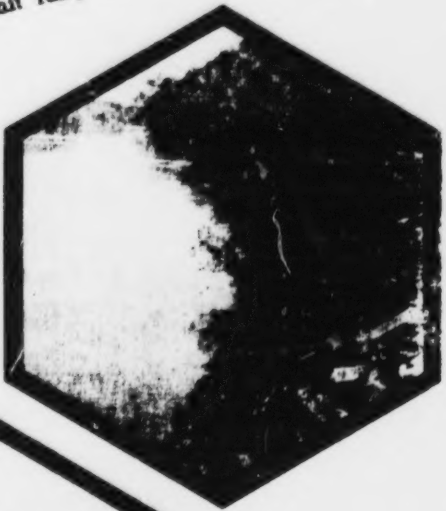

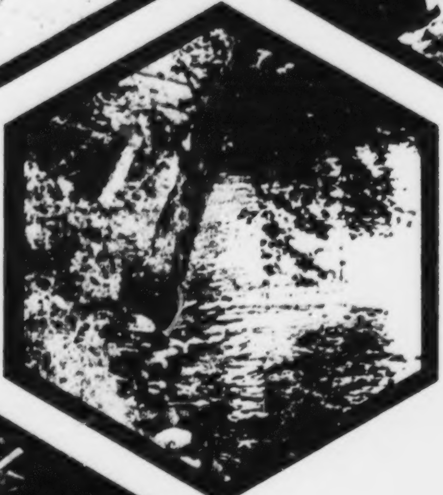

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CREDITS

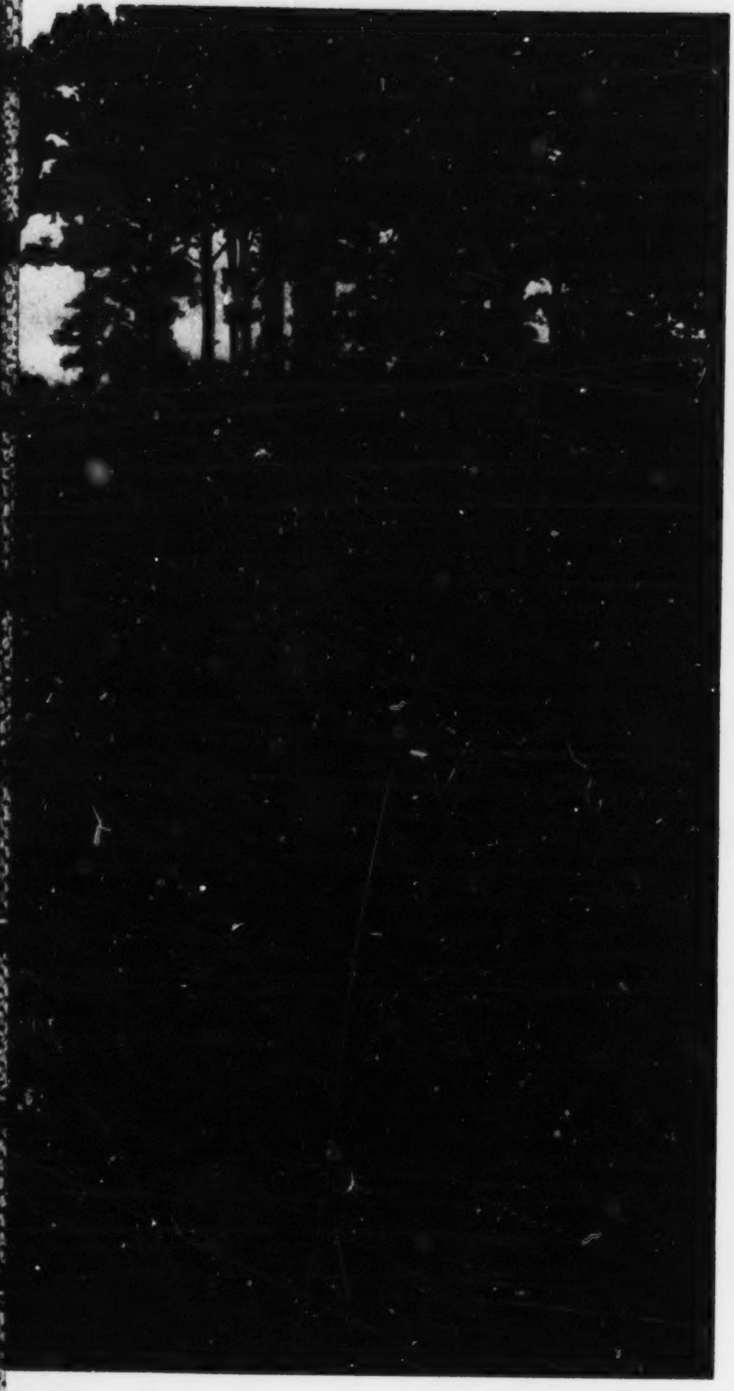
Prepared by: U.S. Army Engineer
Waterways Experiment Station,
Vicksburg, Mississippi 39180

Written by: Malcolm P. Keown,
Environmental Laboratory

Layout and Design: Loriece M. Beall,
Publications and Graphic Arts Division

October 1983

Preface



Large-scale efforts to control soil erosion have been under way in the United States since the "dirty thirties" when wind erosion turned much of the fertile farming area of the Great Plains into a wasteland. Initial soil conservation efforts were directed toward saving topsoil in agricultural areas; however, as the value and use of land near streams increased, the need for effective bank protection techniques quickly became apparent. Many miles of streambank along major waterways have been protected as part of navigation and flood control projects; however, many streams still need bank protection. A 1969 study by the U.S. Army Corps of Engineers showed that of the 7 million miles of streambank in the United States 550,000 miles were experiencing some degree of erosion, while 148,000 miles or 2 percent were being severely eroded. Although 2 percent seems like a small portion of the total length of streambanks in the United States, the annual economic losses occurring as the result of the severe erosion approached $90 million in 1969.

In recognition of the serious economic losses occurring throughout the Nation due to streambank erosion, the U.S. Congress passed the Streambank Erosion Control Evaluation and Demonstration Act of 1974, Section 32, Public Law 93-251 (as amended by Public Law 94-587, Section 155 and Section 161, October 1976). This legislation, called the Section 32 Program, authorized the Corps of Engineers to conduct a 7-year study to examine the causes of streambank erosion, to evaluate the effectiveness of existing and new methods of bank protection, and to prepare documentation for the Congress describing the findings of the Section 32 Program. As instructed in the authorizing legislation, the Corps prepared an Interim Report in 1978 describing work completed through the midterm of the Program. The Final Report was submitted to the Congress in April 1982. After this report was submitted, the Corps was requested to develop a streambank protection pamphlet written in laymen's language to make available to landowners and local governments information gained during the Section 32 Program so that the public as well as the technical community would benefit from the Program. As a result of the request, this pamphlet was prepared by the U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Introduction

Streambank protection is a complex subject. There are no engineering manuals available with construction plans for bank protection projects that are guaranteed to work. Likewise, the U.S. Army Corps of Engineers cannot guarantee that the streambank protection methods discussed in this pamphlet will provide a foolproof approach to save a bank. However, this pamphlet does provide landowners and local governments with general information needed to develop a systematic plan of action for solving a streambank protection problem. By understanding the cause of the problem, matching the problem with a suitable bank protection method, making efficient use of available resources, and initiating a regular maintenance program once the project is completed, the chances for successfully protecting a distressed streambank will be greatly improved.

Although every effort was made to avoid the use of technical language in this pamphlet, some words that are perhaps unfamiliar to the reader must necessarily be introduced to properly discuss items related to streambank protection. The meaning of many of these terms is discussed in the text; however, a glossary is provided at the end of this pamphlet for reference.

The Nature of Streams

Streams, like men, go through a progressive life cycle from youth to maturity. While year-to-year changes can be observed in man, such short-term changes in a stream are not always apparent. As a case in point, consider a small stream flowing through a country village. The stream and its banks have always been a fixed part of the landscape. Suddenly, a bank that has shown no sign of distress since the village was settled sloughs off. The local community wonders what undetected course of events triggered the bank failure and what terrible consequences will follow. What the townspeople do not realize is that the stream is either moving into another stage of its natural life cycle or is responding to some impact caused by man's activity. Prior to developing an understanding of streambank erosion and failure, we must first understand the nature of a stream and its bed and banks. The reader should note here that there is an important conceptual difference between streambank erosion and failure. *Erosion* is the removal of soil particles from a bank surface primarily due to water action. *Failure* is the collapse or slippage of a large mass of bank material into the stream.

A stream should be considered as a delicately balanced mechanism that is gradually maturing. Naturally, landowners and local governments would like to find a stream in a well-balanced condition with smooth, gentle bends, well-vegetated banks free from erosion or failure, and a channel bed that is neither scouring nor building up with sediment. Unfortunately, this pleasant picture is often only a passing scene. A stream, like the plants and animals that live near the stream, must continually adjust to new impacts in order to maintain its balance. These impacts are not only caused by man's activities but are also natural in origin resulting from the maturing process of the stream. When the balance is upset, the stream will respond by some compensating action to bring the stream system back into balance. The most common compensating actions are streambank erosion and bed scour or buildup.

As examples of situations where a stream is thrown out of balance, consider the following common occurrences:

a. A dead tree topples into a small stream. Much of the water flow begins to be diverted by the tree against the opposite bank. At the same time water still moving near the tree slows down and deposits sediment. As sediment builds up around the tree, the velocity of the diverted water increases. Eventually the opposite bank begins to seriously erode and a bar builds up over the fallen tree. Thus, the response of the stream to the fallen tree was realignment of its channel around the tree and erosion of the bank opposite the tree.

b. To increase his planted acreage, a farmer clears off a greenbelt parallel to the stream flowing through his farm. He is then able to plow to the edge of top bank. Unfortunately, the farmer does not realize that rainfall runoff will be channeled down the bank face. As the soil holding the shrubs and grass in place on the bank is slowly eroded away, the natural vegetation is lost, leaving a relatively smooth slope. The stream responds to this loss of "natural roughness" by seriously eroding the surface of the bank during the next flood. After several floods, the farmer not only loses the land originally covered by the greenbelt, but he also loses many valuable acres landward of the greenbelt.

c. A real estate developer is clearing land near a stream. Although many of the large trees are harvested and taken to a saw mill, much of the brush and scrub timber is pushed by bulldozers into the stream channel to be carried away by the next high water. During the next flood, the refuse is indeed carried downstream. This debris in combination with some dead trees that have fallen into the stream form several very large brush and timber piles. When low water conditions return, a few of the piles are positioned such that the streamflow is deflected against the bank toes. As the lower banks are eroded away, the upper banks collapse. Thus, downstream landowners begin losing land along the stream as a consequence of improper land clearing techniques upstream.

d. Rapid urbanization of a watershed's upstream area has resulted in paving and roofing much of the ground surface area originally available for rainfall infiltration. No provisions were made by urban planners to control the runoff rate. As a result, the downstream flow during storms is greatly increased. The response of the stream is to enlarge its channel by bank erosion and bed scour to accommodate the increased flow. As in the case of the real estate development, downstream landowners again lose acreage along the stream because planners did not properly assess the impact of an upstream activity on downstream flow conditions.

The cases discussed above are only a few that could occur when a stream is forced to respond to an impact that is not part of the stream's natural development. Landowners and local governments must realize that most streams are in a continuing state of adjustment (although possibly changing very slowly as compared with the human lifespan) as the stream attempts to compensate for an imbalance at one location by making changes at other locations. Further, when some form of bank protection is put into place the stream will respond to this change. The response may be insignificant or it could be as serious as transferring the erosion or failure problem to a bank downstream. Thus, protection of a bank should be taken seriously, not only in light of successfully protecting the bank, but also considering the impact of the bank protection on the entire stream system.

STREAMBEDS

One of the characteristics of a well-balanced stream is that the elevation of its bed remains relatively constant. If an imbalanced condition develops, the stream could respond in one of two ways: by scouring out its bed or by depositing excess sediment carried by the stream onto the bed. Either condition can lead to problems for the landowner or local government.

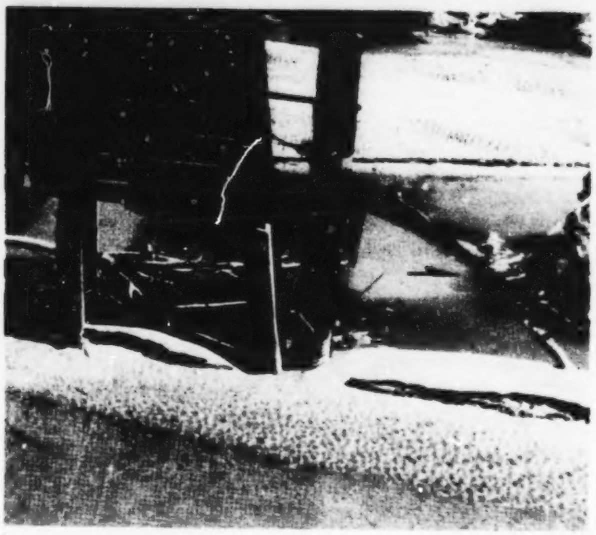
The streambed acts as a foundation for its banks. If streamflow scours out the bed and in the process erodes the bank toe, then the upper bank may no longer have any support, and failure can follow. Alternatively, when a stream is not able to carry its sediment load, material will be deposited on the streambed. As a result, the elevation of the bed will rise, thus reducing the size of the channel. When the next flood comes, the stream will try to enlarge itself to its original size in order to carry the flood flow. As the enlargement process occurs, not only will the bed be scoured out, but both banks may be eroded as well. The most important consideration here is that if the bed of a stream is rising or falling, the investment of time and money into a streambank protection project is questionable because the problem may lie with the bed and not the bank.

Prior to considering construction of a project to protect a streambank, the landowner or local government should first attempt to determine if the streambed is in balance. Typical signs that the bed is not in balance are:

- ☐ Rushing water in an otherwise tranquil stream
- ☐ Waterfalls (often called headcuts)

- ☐ A noticeable increase in channel width caused by caving along both banks
- ☐ Continued raising or lowering of the streambed. This may be observed as a change in bed elevation around bridge piers, dock pilings, etc.

If there is any reason to believe that the streambed in the vicinity of a proposed streambank protection project is not in balance, then professional assistance should be sought before further project planning takes place. If the bed is not in balance, a project should be considered only if the bed elevation can be controlled or if future changes in the bed elevation are anticipated to be minor.



Lowering of the bed elevation around bridge piers may indicate that the streambed is not in balance.

STREAMBANKS

When a bank comes under attack, its ability to resist the attack depends in part on the kind of soil materials found on the surface of and in the bank. These soils are grouped into five major types based on particle size and whether or not the particles tend to stick together (known as cohesion):

Soil Type	*Particle Size Range*	*Cohesive*
Cobbles	greater than 3 inches	no
Gravel	1/4 to 3 inches	no
Sand	microscopic to 1/4 inch	no
Silt	microscopic	no
Clay	microscopic	yes

Only cobbles, gravel, and sand particles can be directly observed by the unaided human eye. Microscopic soil particles can be identified by their cohesive properties. Because clay is cohesive it can be molded into a ball that will not crumble. Silt is not cohesive and will crumble when rolled into a ball.

The soil composition of a streambank can range from simple to very complicated. The simplest case would be a bank where only one soil type is found. At the other extreme, the bank could be an indistinguishable mixture of cobbles, gravel, sand, silt, and clay that would require a laboratory analysis to determine the exact composition. Natural streambanks are often stratified, that is several soil types or mixtures of soil types are found in layers. The break between the layers can be seen on a bank face as a change in color or texture of the soils material if the bank has not become covered by a layer of sediment that has dropped out of the passing streamflow.

Understanding Streambank Erosion and Failure

Constructing a successful streambank protection project without understanding why the bank is eroding or failing probably reflects more on happenstance than common sense. Understanding the principles of streambank erosion and failure requires study and then considerable thought in applying these principles to a particular problem. The time spent in careful study of this section of the pamphlet may mean the difference between construction of a successful bank protection project and a waste of time and money.

As mentioned earlier, the terms streambank erosion and streambank failure are often used interchangeably to describe the condition of a distressed bank; however, these terms are entirely different in concept. *Erosion* occurs when individual soil particles at the bank's surface are carried away. Streambank *failure* differs from streambank erosion in that a relatively large section of a bank fails and slides into the channel. The major causes of *streambank erosion* are:

—Stream currents
—Rainfall
—Seepage
—Overbank drainage
—Obstacles in the stream
—Wave attack
—Freeze-thaw and wet-dry cycles
—Ice and debris
—Changes in land use

Whereas the major causes of *streambank failure* are:

—Swelling of clays due to absorption of water
—Pressure of groundwater from within the bank
—Minor movements of the soil or creep
—Changes in channel shape due to bed scour or erosion of the bank face
—Increase of load on top bank
—Rapid drawdown of water against the bank face

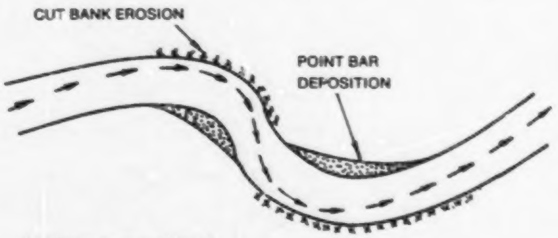
Often, several of these causes work in combination to place a streambank in a distressed condition.

STREAMBANK EROSION

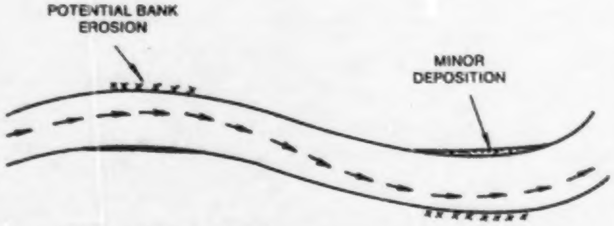
STREAM CURRENTS. Soil particles carried away from a bank by currents (or flowing water) are removed by a *tractive force* which tends to pull particles along with the streamflow. The removal of particles by tractive force is similar to rubbing your hand across a bank surface and picking up soil particles, except that in the case of streamflow, the moving water in contact with the bank rubs against the particles and, once they are dislodged, carries them along with the flow. The strength of a stream's tractive force increases as the water velocity and depth of the stream increase; therefore, erosion is more likely to occur during a flood than during normal flow.

As a particle comes under attack by passing currents, it must be able to resist the tractive force of the streamflow or be carried away. The outcome is dependent on the strength of the attack as counterbalanced by the particle's size and cohesive properties. The larger particles weigh more and are harder to move, thus gravel is less likely to be carried away by swift currents than sand. On the other hand, a clay particle is more likely to stay in place on a bank than a silt particle because of cohesion among clay particles.

As streamflow moves through a bend under normal flow conditions, the velocity increases toward the outside of the bend (or cut bank) increasing the tractive force to as much as twice that in a straight reach of the channel upstream or downstream from the bend. As a result erosion can occur along much of the cut bank, often extending



A. Sharply curved bends.



B. Gradually curved bends.

Sharply and gradually curved bends under normal flow conditions. Arrows indicate the path of the maximum stream velocity. During floodflow this path moves across the channel against the point bar.

Serious streambank erosion is occurring on the right bank of this bend, while a point bar is building up on the left bank.

a short distance downstream from the end of the bend. On the inside of the bend the stream velocity decreases allowing suspended sediments to deposit and build up a point bar. Sharply curved bends are more likely to experience erosion along the cut bank than gradually curved bends. During flood flow the path of maximum velocity moves across the channel against the point bar, often removing material that was deposited during normal flow conditions.

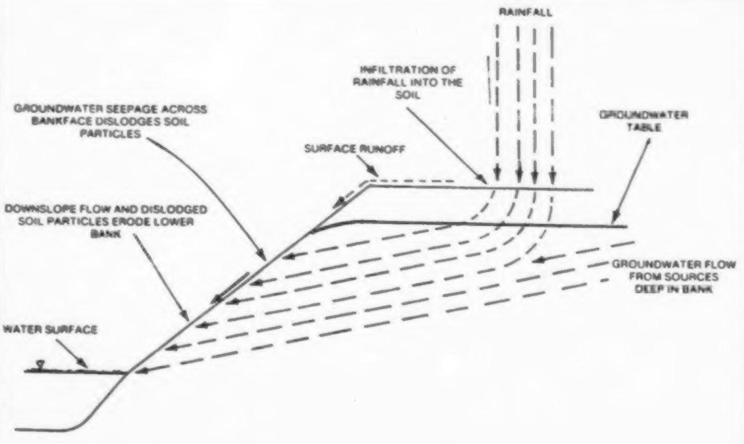
The previous discussion does not suggest that straightening a channel will eliminate erosion problems... quite the contrary. Straightening a channel will shorten it and steepen its bed slope, which in turn may upset the balance of the stream (see "Reroute the Stream," page 31, as a method of bank protection).

RAINFALL. As raindrops strike the earth's surface, the accumulating water can move overland as surface runoff or can infiltrate into the soil. Raindrops splashing on a sloping streambank tend to loosen soil particles and reduce the infiltration capacity of the soil. With the infiltration capacity reduced, more and more of the rainfall will run down the sloped bank which will increase the tractive force of the runoff, and in turn, possibly increase erosion.

If the combined action of splashing raindrops and surface runoff removes particles in thin layers, the soil loss is called *sheet erosion*. If the runoff down the bank slope forms small channels as it carries away soil, the process is termed *rill erosion*. The net effect of sheet and rill erosion, in addition to loss of soil particles that hold vegetation in place, is to remove mineral nutrients and organic matter leaving coarser, less fertile soil behind. Thus, once the surface of a bank has been eroded, natural reestablishment of vegetation may be difficult.

SEEPAGE. The portion of the rainfall that does not move down the bank slope as surface runoff infiltrates downward through the subsurface layers of soil and rock eventually joining the groundwater flow unless the path is blocked by impermeable material. If the infiltrating rainfall does successfully reach the water table, it will move with the groundwater flow to a lower elevation.

Groundwater seepage across the face of a streambank is caused by exposure of the groundwater table. The water slightly below the bank's surface is forced onto the face of the bank by pressure from groundwater movement deeper inside the bank. As seepage occurs, soil particles at the bank's surface may be forced loose. The resulting downslope movement of seepage water and loosened soil particles can further erode the bank. Groundwater seepage can be observed as a *wet* bank face or as piping flow from small holes on the slope.


RAINFALL
INFILTRATION OF RAINFALL INTO THE SOIL
GROUNDWATER SEEPAGE ACROSS BANKFACE DISLODGES SOIL PARTICLES
GROUNDWATER TABLE
SURFACE RUNOFF
DOWNSLOPE FLOW AND DISLODGED SOIL PARTICLES ERODE LOWER BANK
GROUNDWATER FLOW FROM SOURCES DEEP IN BANK
WATER SURFACE

Streambank erosion caused by groundwater seepage across bankface.

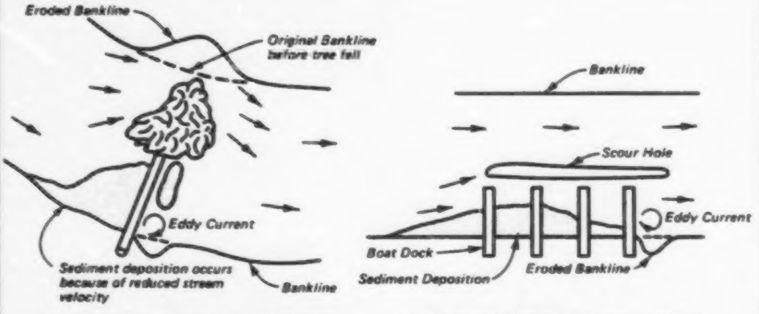
Streambank sheet and rill erosion resulting from overbank drainage.

OVERBANK DRAINAGE. Closely related to the problem of streambank surface erosion due to rainfall and seepage is erosion caused by overbank drainage. Unless properly controlled, overbank drainage can result in severe sheet and rill erosion. Although this problem occurs under natural conditions, it is more frequently associated with land clearing and plowing near top bank where provisions have not been made for surface drainage control.

OBSTACLES IN A STREAM. The potential for bank erosion can be substantially increased or decreased when man-made or natural obstacles are built in, dumped in, or fall into a stream. The word *obstacles* is used here in a very broad sense to include dams, bridge piers, boat docks, rubble, fallen trees, etc. These obstacles can cause significant changes in streamflow characteristics as well as changes in the location of the channel and in the amount of erosion or sediment deposition occurring in the bed or on the banks of the stream. Obstacles in a stream can be divided into three general categories: obstacles that

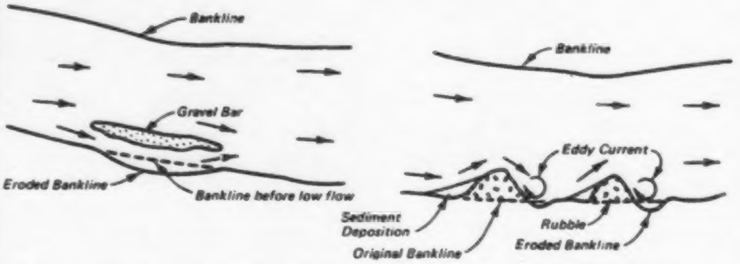
—are built completely across the stream
—constrict the streamflow
—deflect the streamflow

The most frequently encountered man-made obstacle that is built completely across a stream is a dam. Dams are built for a wide range of positive objectives including water conservation, flood control, power generation, navigation improvement, sediment retention, and recreation. Because most dams are operated as multipurpose structures, their effect on streambank erosion, if any, is difficult to assess. Landowners or local governments having a bank erosion problem upstream or downstream from a dam should seek professional assistance during development of a plan to protect the eroding bank. This will insure that the selected bank protection method will work hand in hand with operation of the dam so that maximum protection benefits will be realized for the time and money invested in the project.



A. Fallen tree across a small stream forces erosive currents against one bank and causes sediment deposition upstream and downstream from the tree. An eddy current erodes the downstream bank.

B. Sediment deposition occurs along a series of docks due to reduced stream velocity through the docks. A scour hole has developed at the ends of the docks and downstream from the last dock.



C. Erosive currents are deflected against bank by gravel bar exposed during low flow.

D. Irregular bankline caused by dumped rubble sets up eddy currents which erode bank. Sediment deposition is occurring upstream from the rubble.

Obstacles in a stream can deflect current flow causing complex erosion and sediment deposition patterns.

Streamflow constrictions can be either natural in origin or man-made such as a bridge. The net effect of any constriction is a reduction in the width of the stream. When a constriction attempts to pass flow, the water approaching the upstream end of the constriction begins to move faster which in turn raises the potential for streambank erosion both upstream from and through the constriction. As the fast-moving water leaves the constriction, it spreads out. If the *spreading* water or main flow cannot follow the bankline, a rotating current, called an *eddy*, will be set up next to the bank. The eddy can cause severe erosion if the bank is not properly protected. Further downstream from the end of the constriction, the main flow will contact the bank, possibly causing additional erosion.

Typical obstacles that deflect streamflow are fallen trees, rubble, boat docks, sand and gravel bars, irregular banklines, etc. If the obstacle is aligned with the stream current such that erosive currents are deflected away from the bank and eddy currents are not set up, then the obstacle will protect the bank and possibly cause deposition. On the other hand, if stream currents are deflected against one of the banks by the obstacle or if eddy currents develop, then serious bank erosion can occur.

WAVE ATTACK. Passing boats or wind can set up waves on a stream. As the waves come into contact with a streambank the repeated agitation tends to dislodge soil particles. Wave attack can be an erosion force on streams with heavy commercial traffic and recreational activity or on streams with large areas of open water where the wind can build up waves. Wave attack is generally not a serious problem on small streams.

FREEZE-THAW AND WET-DRY CYCLES. In many parts of the United States temperature variations during the winter months can cause banks to undergo one or more freeze-thaw cycles. After the surface of a bank has frozen, an ice layer often forms below the surface. As the ice layer grows thicker, the surface bank materials are pushed outward. When thawing occurs the bank materials settle back into position in a loosened and more erodible condition.

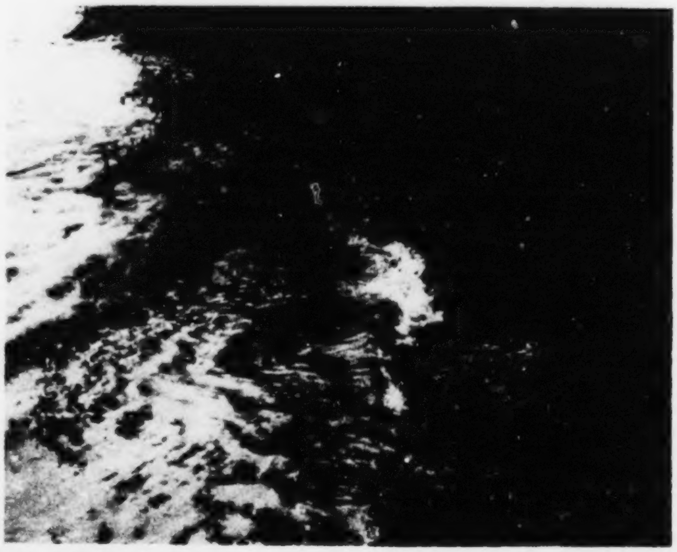
Drying of exposed wet clay and silt on a streambank slope can lead to shrinkage and cracking of the material near the surface, forming a layer of soil that can be easily eroded. During the next period that water moves over the bank face all or part of the layer may be removed. As the newly exposed material dries out the cycle can repeat itself.

ICE AND DEBRIS. After formation of an ice pack, the ice remains essentially *in place* during the winter months and causes very little streambank erosion. As the pack thaws in the spring, the ice breaks up into chunks and begins floating downstream. During this period, the amount of damage to the streambanks is largely determined by whether the banks are still frozen or have begun to thaw. Frozen banks generally sustain little soil loss; however, structures such as boat docks, as well as trees and other vegetation, may be stripped away from the frozen banks by the impact of the ice chunks or pressure buildup from an ice jam. If the chunks of pack ice pass through a channel where the banks have already thawed, severe bank erosion can occur, mainly due to grinding of the ice against the streambank (abrasion). Debris, like ice, can cause streambank erosion by either abrasion or impact. The most common debris found in streams are the remains of fallen trees.

CHANGES IN LAND USE. Under natural conditions, a bank may show no signs of erosion for many years. On the other hand land-use changes that influence streamflow past the bank and the amount of sediment in the flow can cause an otherwise erosion-free bank to rapidly become a serious problem.

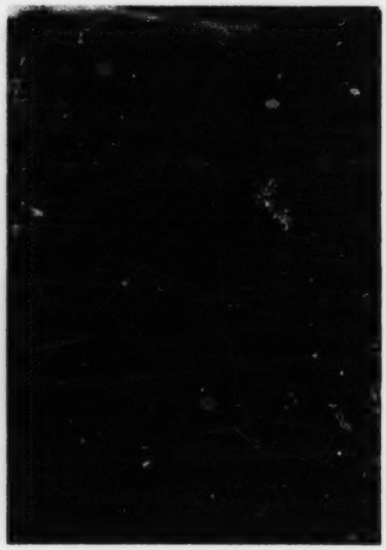
The increasing area needed for urbanization and the continued clearing of forest

Wave attack on a streambank.



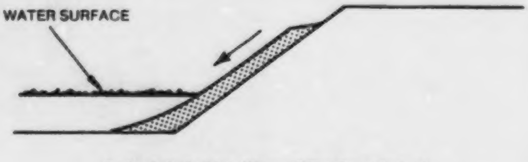
Ice generally remains in place during the winter months and causes very little streambank erosion.

Debris can cause streambank erosion due to abrasion or impact.

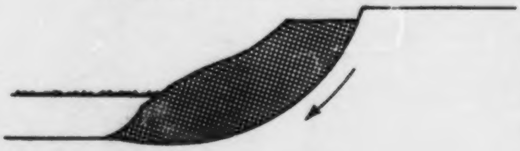


ABOVE: Continued urbanization has left many areas without the vegetation cover needed to effectively control rainfall runoff. BELOW: Clearing land for agricultural purposes can significantly increase the sediment load of nearby streams.

(Photos provided by Soil Conservation Service)



A. A relatively thin soil layer sliding down the bank.



B. A large mass of soil that slips along a curved path deep in the bank. Arrow indicates direction of soil movement.

Two basic types of bank failure.

and grasslands for agricultural purposes have dramatically changed the land use in many parts of the United States. Statistics compiled by the U.S. Department of Commerce indicate that nearly half of our surface soils have been disturbed and are potentially erodible if not properly managed. Further, much of the land now in urban areas is no longer available for rainfall infiltration due to the construction of buildings, highways, and parking lots.

The inevitable results of removing vegetative cover, disturbing surface soils, and decreasing the area available for rainfall infiltration are downstream flooding and increased sediment loads. Streambanks that once suffered no erosion now are subjected to greater stream velocities during unprecedented flood flows. In addition, as the flood flow subsides, the excessive sediment load may be deposited on the bed of the stream, thereby reducing the channel's flood-carrying capacity. If the deposited material is not scoured out before or during the next flood, the stream may attempt to widen itself to carry the flow, thus further eroding the banks.

STREAMBANK FAILURE

A streambank will remain stable as long as those factors resisting failure are stronger than those factors that could cause the bank to collapse, or in the language of the engineer: "The shear strength of the bank soil must be greater than the shear stresses in the bank." Two basic types of bank failures can occur:

- ☐ A relatively thin soil layer sliding down a bank
- ☐ Or a large mass of soil that slips along a curved path deep in the bank

Regardless of the type of failure that occurs, the general conclusion is that "the bank sloughed off." A decrease in the shear strength of the soil or an increase in the shear stresses in the bank can individually or in combination lead to a bank failure.

DECREASE IN SHEAR STRENGTH. The major causes for a decrease in bank soil shear strength are:

- Swelling of clays due to absorption of water
- Increased pressure of groundwater from within the bank
- Minor movements of the soil or creep

Swelling clays or indications that excessive groundwater pressure is building up in a bank cannot be directly observed. Evidence of soil creep can be observed by the development of bank cracks that generally run parallel to the stream.

INCREASE IN SHEAR STRESS. Increases in shear stress that can lead to bank failure are most commonly the result of

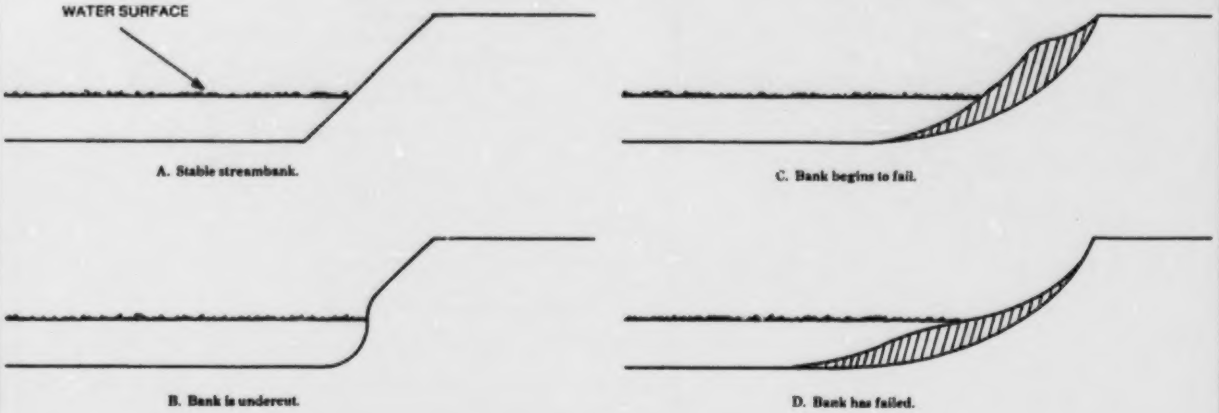
- Changes in channel shape due to bed scour or erosion of the bank face
- Increase in the load on top of the bank (buildings, roads, etc.)
- Rapid drawdown of water against the bank face

As the bed of a channel is scoured out by passing streamflow, the height of top bank above the bed increases. The bank may fail if its height continues to increase (see photo next page). Erosion of a bank face can increase shear stress in two ways: by undercutting the toe that buttresses the bank or by steepening the bank slope.

During periods of high water, banks can become saturated by inflow from the stream, by infiltration due to rainfall or

Streambank sloughing.

Development of bank cracks running generally parallel to a stream may indicate that soil creep is taking place. This type of movement decreases the shear strength of the soil and increases the probability of a bank failure.



A. Stable streambank.

C. Bank begins to fail.

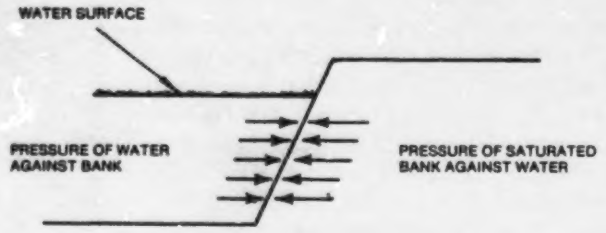
B. Bank is undercut.

D. Bank has failed.

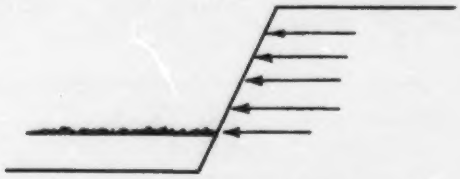
Failure of streambank due to undercutting at the toe.

runoff, or by groundwater sources deep in the bank. When the bank face is covered by water, a pressure balance exists between the water in the channel and the weight of the saturated bank. This balance helps keep the bank in place. If the pressure of the stream water is suddenly removed by a rapid drop in water surface elevation (or *rapid drawdown)* and the soil cannot drain quickly, a pressure imbalance will exist. This imbalance may cause the streambank to slough off if the bank does not have sufficient shear strength to resist failure. Bank failures caused by rapid drawdown are most likely to occur as floodwaters recede or when a streambank is subject to water-surface-elevation fluctuations resulting from operation of a stream-regulating structure.

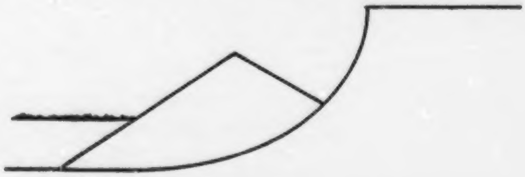
Bed scour in effect raises the height of top bank which in turn may lead to bank failure.


WATER SURFACE
PRESSURE OF WATER AGAINST BANK
PRESSURE OF SATURATED BANK AGAINST WATER

A. Pressure balance of stream water and saturated bank.



B. If the water surface elevation drops rapidly and the bank cannot drain quickly, a pressure imbalance will develop.



C. Bank may fail because of pressure imbalance.

Bank failure due to the water against a saturated bank being lowered faster than the bank can drain (rapid drawdown).

Developing a Plan of Action to Protect a Streambank

This pamphlet can be used to guide the landowner and local government in developing a plan of action to protect a distressed streambank. Such a plan of action has eight basic steps:

1. Determine why the streambank is in a distressed condition
2. Decide if the bank is worth protecting
3. Inventory available resources
4. Select a bank protection method
5. Develop a project plan
6. Obtain a permit
7. Construct the project
8. Inspect and maintain the project

Following this plan of action cannot guarantee that the progressive loss of a distressed streambank can be slowed or halted. However, by using an organized approach to deal with a bank erosion or failure problem, the chances of success will be improved and the possibility of a fruitless investment of time and money greatly reduced.

Step 1

DETERMINE WHY THE STREAMBANK IS IN A DISTRESSED CONDITION

The search for clues to determine why a streambank is eroded or why it failed is often an after-the-fact investigation. In most instances healthy streambanks warrant only a passing glance. When a bank becomes distressed and public safety or loss of tangible assets becomes a factor, only then does the typical landowner or local government become concerned about the well being of the bank.

Many distressed streambank problems start during floods. Because of high water, direct observation of developing bank erosion or failure is often impossible. Only after the high water has receded can an attempt be made to determine why the bank eroded or failed. In many cases, the clues must come from inspecting a raw steep bank whose surface vegetation has been stripped away leaving only large trees leaning toward the stream with parts of their root masses exposed. What happened? Did flood flow scour out the toe leaving an unsupported bank... hard to tell if the bank sloughed off and covered up the eroded toe. Did the stream current erode the bank face back to a slope steeper than the bank could stand ... impossible to determine since the erosive action could not be watched. Did clay swelling in the bank due to floodwater inflow cause the bank to fail... a difficult problem to assess since clay swelling cannot be observed.

Obviously, these are cases where professional assistance is needed... but where does this leave the landowner or local government when aid is not available? The answer to this problem is to avoid trying to identify the cause(s) of streambank erosion or failure strictly on the basis of an after-the-fact investigation. Putting together a well-documented history of the development of a distressed bank cannot be based on a single inspection visit. Streambanks should be visited regularly to check for *warning flags* that may indicate troubles are ahead. Signs to look for are

—Exposed soil

—Loss of vegetation and fenceposts

—Sheet or rill erosion resulting from rainfall, overbank drainage, or seepage

—Cracks in the bank or in the area immediately behind top bank

—Overhanging banks

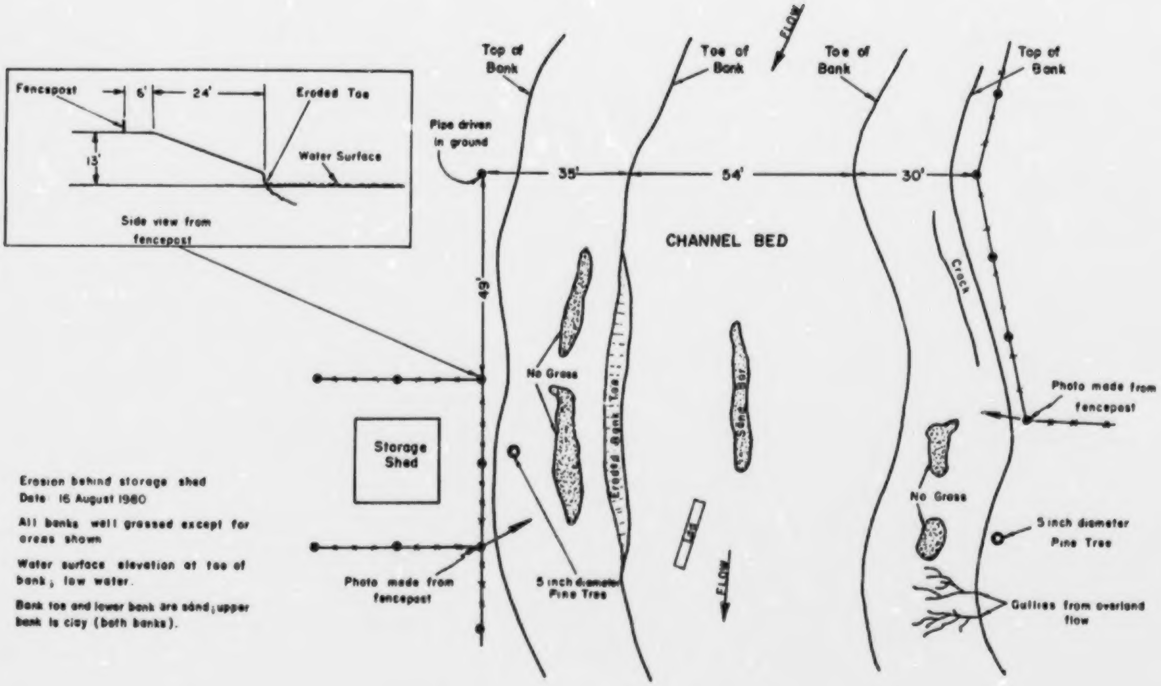
—Undermined trees with exposed roots

—Scour along the bank toe

—Changes in channel bed elevation

—Wave action

—Rapid drawdown


Top of Bank
Toe of Bank
FLOW
Toe of Bank
Top of Bank
Fencepost
6'
24'
Eroded Toe
13'
Water Surface
Side view from fencepost
Pipe driven in ground
35'
54'
30'
CHANNEL BED
49'
Crack
No Grass
Eroded Bank Toe
Sand Bar
Photo made from fencepost
Storage Shed
No Grass
5 inch diameter Pine Tree
Photo made from fencepost
5 inch diameter Pine Tree
FLOW
Gullies from overland flow

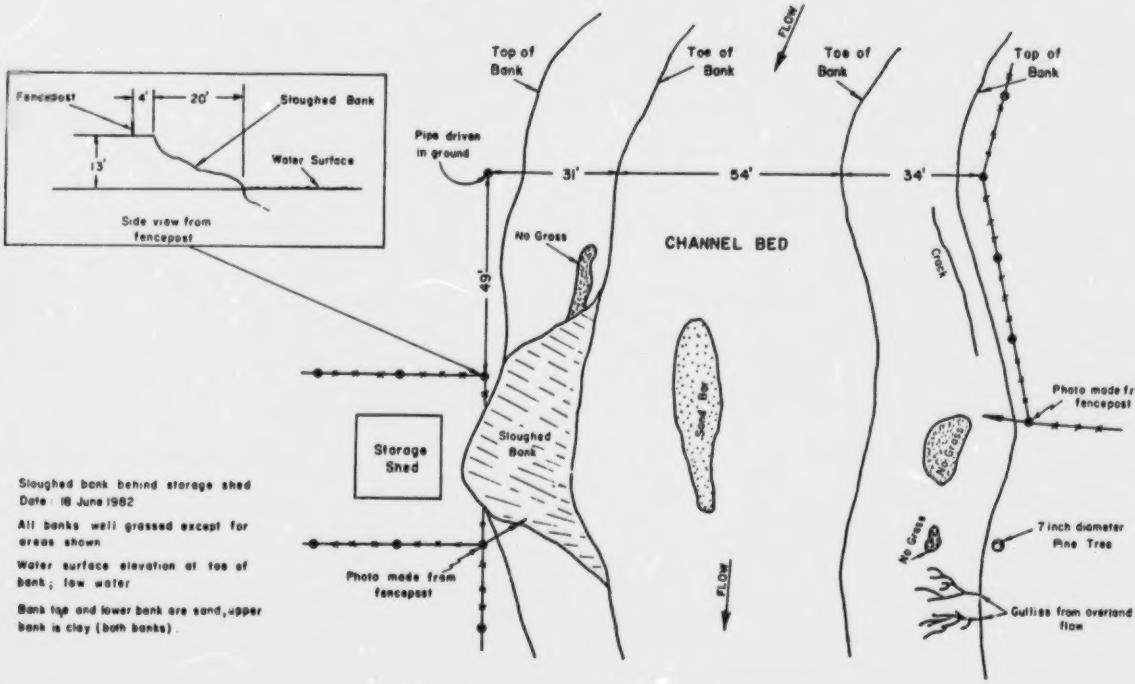
Erosion behind storage shed
Date 16 August 1980

All banks well grassed except for areas shown

Water surface elevation at toe of bank; low water.

Bank toe and lower bank are sand; upper bank is clay (both banks).

Sample map sketch showing eroded bank toe.


Top of Bank
Toe of Bank
FLOW
Toe of Bank
Top of Bank
Fencepost
4'
20'
Sloughed Bank
13'
Water Surface
Side view from fencepost
Pipe driven in ground
31'
54'
34'
No Grass
CHANNEL BED
49'
Crack
Sand Bar
Photo made from fencepost
Storage Shed
Sloughed Bank
No Grass
No Grass
7 inch diameter Pine Tree
Photo made from fencepost
FLOW
Gullies from overland flow

Sloughed bank behind storage shed
Date: 18 June 1982

All banks well grassed except for areas shown

Water surface elevation at toe of bank; low water

Bank toe and lower bank are sand, upper bank is clay (both banks).

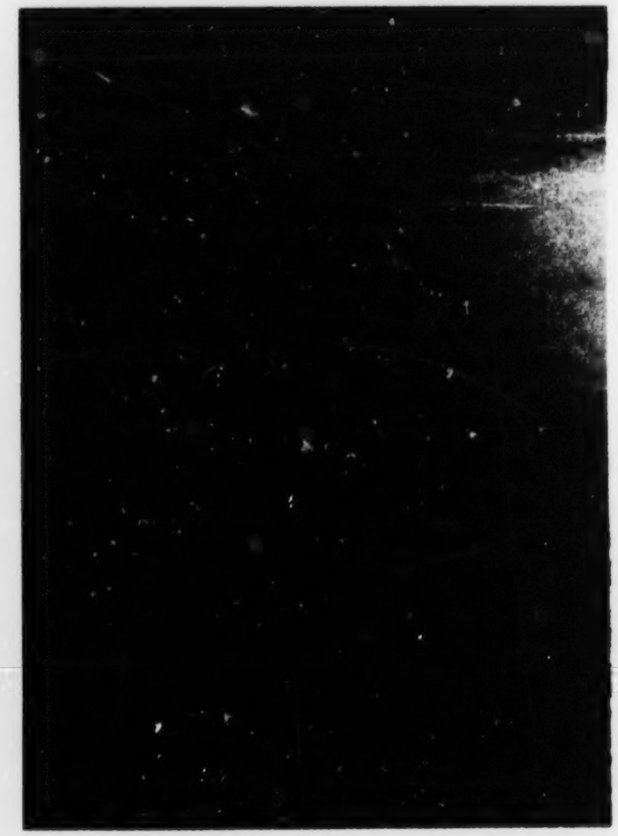
Sample map sketch showing sloughed bank resulting from eroded toe.

—Increased load on the top of the bank
—Higher flood stages than have occurred in past years
—Logs, debris, and sandbars in the channel that could deflect eroding currents into the bank

These types of problems should be recorded during an inspection visit on a dated map sketch of the site. This sketch should show the location of the streambanks (top and toe), eroded areas, vegetation, fence lines, buildings, sandbars, logs, debris, and any streambank protection works already in place. Side views of the bank should also be made at various locations. Be sure to reference all side views to some fixed point such as a tree or fence post. Photographs should be taken (and dated) and the locations from which the photographs are made shown on the sketch. Additional visits should be made on a regular basis, including once during low water season (normally during the summer or fall) and once immediately after any high water period. If the landowner or local government has several miles of streambank to monitor, detailed inspection visits probably cannot be conducted along the entire length of the bank. Those sections of the bank that are particularly susceptible to erosion or failure (see "Signs to look for" above) should be visited regularly, whereas stable banks can be inspected as time allows.

Even if there are no problems observed during a visit to the streambank, a dated map sketch should still be made for future reference. If the day comes that the bank does become distressed, this historic information could provide help in determining the cause of the problem and what measures would be most effective in dealing with the erosion or failure. Hopefully, the solution will be obvious, such as placing concrete rubble at the foot of the bank to prevent erosion due to stream currents. On the other hand, the problem could be more subtle or of a larger extent and will require professional guidance. The sketches and photographs made of the bank over past years will provide the professional engineer or scientist with invaluable information needed to make sound recommendations for protecting the distressed bank.

Streambanks should be photographed to document developing problems and visited regularly to check for signs of bank erosion or failure. Ideally, visits should be conducted by two or more persons, not only for safety reasons, but also for recalling site conditions at a later date.



Another source of historic information is aerial photographic surveys conducted by the U.S. Department of Agriculture (USDA), Agricultural Stabilization and Conservation Service (ASCS). Photographs are made every 6 to 10 years over most agricultural areas. A check should be made with the local ASCS office to determine if photography is available and how it can be ordered. Costs are usually minimal.

Landowners and local governments must decide if bank is worth protecting.

The suggestions made in the preceding paragraphs do not provide much guidance for landowners and local governments who do not have the advantage of historic records but need to identify the cause(s) of streambank erosion or failure. If study of this pamphlet and the existing condition of the bank do not provide the clues needed to determine why the problem developed, then the last recourse is to draw on experience gained through solutions of similar problems that have occurred in the past, possibly on the same stream or in the general area of the distressed bank. Professional assistance will be needed in many cases to extend available past experience to a specific problem.

Step 2

DECIDE IF THE BANK IS WORTH PROTECTING

If examination of a distressed bank condition indicates that the problem is not related to the rise or fall of the streambed elevation (see Streambeds, page 5), and those causes that have placed the bank in a distressed condition can be identified, then the landowner or local government must decide if action should be initiated to protect the bank. Unfortunately, the question is generally not "Should the bank be protected," but instead is "Is the bank worth protecting?" or, turning the question around, "What is the risk if the bank is not protected?"

Consider the following situations:

a. Farmer Brown has 50 acres of bottomland that he occasionally uses for livestock grazing. The stream adjacent to the pasture bottomland has been slowly eroding the bank away for the past 15 years. A local contractor estimates that Brown will have to spend at least $5,000 to protect the bank. Downstream from the erosion site, Farmer Brown is gaining some acreage due to sediment deposition. Although this area is not building up as fast as the upstream pasture is being lost, it is suitable for grazing—should Brown invest $5,000 to protect the eroding bank?

b. Dr. Jones has a home valued at $150,000 on the bank of what is normally a small stream. An unusual number of floods over the past 5 years have eroded the bank to within 50 feet of Jones' home. An engineering firm studied the problem and determined that the flooding is probably caused by accelerated runoff from the parking lot of a large shopping center upstream from Jones' home, although the evidence is not conclusive. Further, the engineers recommend protecting Dr. Jones' bank by constructing several dikes extending into the stream. These structures would deflect eroding currents away from the bank and would slow down the water flow near the bank. As the water slows down, the sediment it carries should be deposited between the dikes and on the eroding bank. If sufficient sediment deposition occurs the dikes will be covered up and the bank restored to its original condition. The only problem with this approach is that the eroding currents deflected away from Dr. Jones' bank by the dikes may cause erosion on the opposite bank. This possibility could bring about legal action. Should Dr. Jones have the dikes built . . . consider another approach to protect the bank . . . move his home . . . abandon the home . . . tough decision.

c. Mr. Smith purchased 50 acres of hardwood forest adjacent to a stream for $1,000 per acre. Foresters told Smith that he will have $20,000 to $30,000 worth of marketable timber in 10 years with inflation discounted if his stand does not become diseased which is a common problem in the area. A year after Smith purchased the land, he realized that the streambank had receded 10 feet; at that rate 10 percent of his timber stand would be lost by the time the timber matures. The local Soil Conservation Service District Conservationist tells Smith that he could place a mattress made of used tires on the bank for $10,000 which should control the erosion. So Mr. Smith is faced with investing $10,000 to save 5 acres of land (which will appreciate in value) and $2,000 to $3,000 worth of timber provided the stand does not become diseased ... another tough decision.

d. The city of Pickettville is located on State Road (SR) 32 which parallels the bank of a large waterway. Pickettville's major water and gas mains were placed under SR 32. Several major floods have seriously eroded the bank and now endanger SR 32 and the utility lines for a distance of one-half mile along the bank. During past floods, city, county, and state crews have dumped enough rubble down the bank to save SR 32, but all agree that sooner or later the river will take the road. After several years of discussion the City Council wrote the Corps of Engineers for assistance. The District Engineer authorized a study which indicated that the bank could be stabilized. However, for one-third of the cost of the streambank protection works, SR 32 and the utility lines could be relocated. Further, emergency funds could be made available for this relocation, but sufficient funds were not available for construction of the more expensive bank protection works. The Corps of Engineers report also predicted that the bank could stand only one or two more major floods before SR 32 and the utility lines would be lost. After these losses, no further significant city or private damages would occur within the foreseeable future. The City Council finds that the community is strongly opposed to the proposed relocation because SR 32 would have to be rerouted through the city's park and across the playground of the elementary school. With an election on the horizon, the City Council has reservations about the relocation. On the other hand, if the bank washes out next spring, the Council will be blamed for not proceeding with the Corps of Engineers proposal.

A community or group effort to protect a distressed streambank can often jointly benefit everyone involved.

Each decision to determine if a bank is worth protecting is unique. No step-by-step guidelines can be laid out for reaching this decision. Tangible and intangible assets must be weighed against the anticipated costs of proposed solutions and, in some cases, legal and political consequences. Thus, with all of these factors under consideration, the final decision to protect or not protect a bank must ultimately rest with the landowner or local government.

Step 3

INVENTORY AVAILABLE RESOURCES

Once the decision has been made to protect a distressed streambank, an inventory should be conducted to determine what level of group or community cooperation should be expected and to identify available financial, technical, manpower, equipment, and construction material resources. The results of this inventory will determine to a large extent what types of streambank protection works are feasible.

GROUP OR COMMUNITY COOPERATION. Distressed streambanks rarely begin and end at property lines, thus bank

The SCS inspecting a distressed streambank...

...recommendations are made...

...financial assistance may be provided by the ASCS.

erosion or failure problems are, in most cases, group or community problems as opposed to an individual problem. Prior to initiating individual action to protect a streambank, adjacent landowners should be contacted. Possibly a cooperative effort can be organized that would jointly benefit everyone involved. Otherwise, a well planned and properly constructed streambank protection project could be damaged or lost because erosion or failure continues on adjacent property. By pooling resources, a much lower cost per foot of bank protected may result from a group or community effort. In addition the bank may be effectively protected for a longer period of time because the entire length of an eroding or failing bank was protected as opposed to only a portion of the bank...or put another way, construction of a streambank protection project without proper assessment of bank conditions upstream and downstream from an individual property owner's distressed bank may be a commitment to project failure.

Another important advantage of group or community cooperation is legal protection. For example, an improperly aligned streambank protection project could direct stream attack against a downstream neighbor's bank, or the project could present a safety hazard or be considered as an eyesore. If such undesirable consequences can be directly linked to an individual's streambank protection activities, he may be found liable for damages. Group or community agreement regarding the method selected to protect a bank should be reached prior to construction. A legal contract relieving all of the principals involved of any tangible or intangible damages resulting from a streambank protection effort can help to avoid strained relations and legal problems.

FINANCIAL AND TECHNICAL ASSISTANCE. Assistance for landowners and local governments may be available from the U.S. Army Corps of Engineers, the USDA Soil Conservation Service (SCS) and the ASCS, and various state and local agencies. Under present law, the Corps of Engineers cannot provide financial assistance for a streambank protection project aimed solely at protecting private property; however, the Corps of Engineers can participate in the funding of certain kinds of emergency protection work under the authority of Section 14 of the 1946 Flood Control Act (Public Law 79-526). The Corps of Engineers District having jurisdiction over the stream on which the landowner or local government has a bank protection problem should be contacted to determine if funding is available under the authority of Section 14. The addresses and telephone numbers of the Corps of Engineers Districts are listed on page 55; a map is also provided showing district boundaries (page 57).

Another source of assistance is the SCS. The SCS has an office in each state capital and generally a local office in each county (a telephone number is listed in most directories). At a landowner's or local government's request, the SCS will usually inspect a distressed streambank provided the inspection request has been properly coordinated through the local soil and water conservation district. If a problem exists that warrants remedial action, the SCS will make recommendations and assist in developing a plan to correct the problem. Some financial assistance may be available through the ASCS. The funding level is based on an annually determined percentage of the total project cost not to exceed

$3,500. The SCS may assist the landowner in making an application for financial aid through the ASCS if the project is eligible.

The Water Resources Divisions of the U.S. Geological Survey (USGS) in each state are sources of valuable information useful for planning. A variety of geologic and topographic maps is available from the USGS (contact the USGS National Cartographic Information Center at 507 National Center, Reston, VA, 22092, telephone 703-860-6045). They also can furnish data on streamflow and water-surface elevations at many locations (the Corps of Engineers may also have data). Other possible sources of technical information and assistance are state geological surveys and state departments of public works, transportation, and natural resources. Some local agencies may also be of assistance.

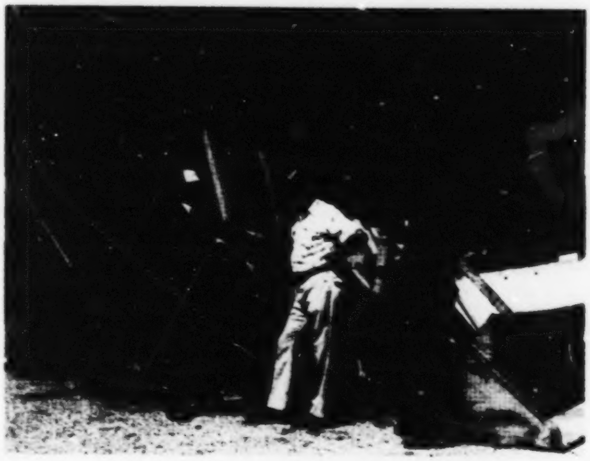
MANPOWER, EQUIPMENT, AND CONSTRUCTION MATERIALS. If good group or community cooperation is developed, sound technical advice is provided, and sufficient financial assistance is authorized, then the availability of manpower, equipment, and construction materials may not be important considerations. Unfortunately, these optimum circumstances are rarely realized. A more realistic situation is some technical advice, no financial assistance, and the responsibility for rounding up manpower, equipment, and construction materials being left entirely to the landowner or local government. Thus, the type of streambank protection works to be constructed are, in part, dependent on the resourcefulness and innovation of the builder.

Once manpower, equipment, and construction material resources are inventoried, project planning may be pretty well boxed in; that is, if manpower is limited, then labor intensive streambank protection works are not feasible ... if equipment such as trucks, tractors, and graders are not available, then movement of large amounts of soil and rock will not be possible ... if materials needed to construct the project cannot be economically obtained, then other solutions to the streambank erosion or failure problem must be considered. Obviously the manpower-equipment-construction materials inventory is essential to the success of the project; thus, no stone should be left unturned. Solicit manpower from neighbors, friends, Boy Scouts looking for a community service project, etc. If suitable construction materials are not available, look for substitutes — although quality stone riprap may be desirable for a project, consider substituting broken pavement, concrete blocks, brick, or tile (provided they are heavy enough not to be washed away by the streamflow). If the timber needed to construct a bulkhead is too expensive, consider rounding up used tires from local service stations, and then stacking the tires to form a bulkhead. Landowners and local governments, who are willing to negotiate, substitute, and scrounge, stand a better chance of constructing a successful streambank protection project than a builder who takes the attitude of "we'll make do with what's behind the barn."

Step 4

SELECT A BANK PROTECTION METHOD

The selection of a method to protect a distressed streambank is the key step in the "eight step plan of action." At this point, the landowner or local government has hopefully determined the cause and extent of bank distress, has decided that the bank is worth protecting, and has carefully conducted a resource inventory. The problem and available resources must now be



Equipment and operators can sometimes be secured gratis or for a nominal fee from sympathetic local interests.

matched against a bank protection method that will effectively control further loss of the bank. An improper match may commit the project to failure before construction is ever started.

Prior to making the final selection of a method to protect the bank, every avenue of technical assistance should be explored and all legal ramifications carefully weighed. Consideration should be given to every feasible type of streambank protection. Approaches that have proven to be especially suitable for use by landowners or local governments are discussed on pages 29-48. The text, photographs, and sketches describing these approaches should be studied in detail to appreciate the full range of alternatives. When all possible information is in hand, the selection must be made; once past this point the resources are committed.

Technical advisers will almost always initially recommend that permanent protective works should be built but understand that landowners and local governments cannot always afford the large costs. This means there may have to be departures from standard designs to provide some degree of protection against erosion or failure. These compromises will tend to decrease the initial cost of construction; however, higher maintenance costs and shorter project life are inevitable. The danger is to underdesign the project to cut costs and as a result risk total failure.

Step 5

DEVELOP A PROJECT PLAN

Improper project planning can result in problems during the entire period of construction and beyond. Time invested in detailed planning prior to beginning construction will yield dividends throughout the life of a project. Plans should be laid out in steps; an example of a typical plan is:

- ☐ Prepare drawings of the construction site showing detailed top, front, and side views of the proposed bank protection structure; a technical advisor often handles this job.

Time spent in project planning will yield dividends throughout the life of the project.

- ☐ Arrange for financing the project. Be aware that a good project plan has maintenance possibilities included; thus, future funding requirements should be anticipated during preliminary planning.
- ☐ Draw up and sign any legal contracts needed to protect the landowner(s) or local government.
- ☐ Investigate potential adverse environmental impacts that may result from construction of the project (see comments below).
- ☐ Apply for all permits required for construction.
- ☐ After all required permits are approved, determine when construction can begin and when it should be completed. If there is a lengthy delay between initial planning and construction, project plans should be reviewed to determine if the selected streambank protection method will still be effective.
- ☐ Insure that road access to the site is available.
- ☐ Make arrangements to secure all materials needed for construction and be sure that delivery can be made before the materials are needed at the site; prepare accessible areas at the site where the materials can be stored.
- ☐ Determine that the construction period will be properly coordinated with manpower and equipment commitments, weather conditions, and low water.

Although environmental impacts may not be of immediate interest to a landowner or local government, this important consideration should be included in project planning even if the only motive is maintaining community harmony. Typical examples of projects that would probably be viewed as having adverse environmental impacts are:

a. Automobile bodies placed on a bank across the stream from an exclusive housing area; the homeowners may claim that the bodies are not only an eyesore but will lower the value of their homes. (*The use of automobile bodies is not recommended in any form for streambank protection.*)

b. A used-tire mattress constructed by a farmer on a bank above a sand berm that is used as a beach during low-water periods; bathers may say the mattress denies recreational access to the beach because a mattress is difficult to walk over. The farmer views bathers as trespassers but is not sure where his property line is because the stream has changed its course several times over past years.

c. A set of fences built from a bank toward midstream; although the fences will deflect the current away from the bank and encourage sediment deposition, pleasure boaters may regard the fences as a hazard.

If there is any doubt as to whether a proposed bank protection method may raise a negative reaction, then adjacent landowners or the community should be made aware of project plans well before commitments are firmed up. (This may have already been done as part of Step 3.) If a problem does become apparent, perhaps a modification or alternative to the project plan can be developed such that the adverse impact can be eliminated or minimized and the landowner or local government will get the streambank protection needed.

On the other hand, construction of a streambank protection project could have positive environmental impacts such as reducing the sediment load of a stream by protecting an eroding bank or improving the appearance of a raw bank by grading it off and planting grass. Hopefully, consideration of impacts will be built into the landowner's or local government's project planning process such that the environment is improved because a bank was protected.

Step 6

OBTAIN A PERMIT

A Corps of Engineers permit is usually required if a landowner or local government plans to build a streambank protection project. The Corps of Engineers was assigned the responsibility for issuing permits by the Congress under authority of Section 10 of the River and Harbor Act of 1899 to prevent alteration or obstruction of navigable waterways in the United States.

Water pollution and maintenance of freshwater supplies have become serious problems in the past few years. Responding to this need, the Congress passed legislation requiring permits for the discharge of dredged or fill material into the navigable waters of the United States (Section 404 of the Federal Water Pollution Control Act Amendments of 1972, as amended by the Clean Water Act of 1977). Administration of this permit program was also assigned to the Corps of Engineers. In 1975, the U.S. District Court for the District of Columbia directed the Corps of Engineers to extend its responsibility to regulate the discharge of dredged or fill material under Section 404 to all *Waters of the United States*.

What does this legislation mean to the landowner or local government trying to protect a streambank? The term *Waters of the United States* includes all dry land and water-covered areas below the ordinary high water marks on navigable and non-navigable streams. Thus, any proposed bank protection project requiring soil excavation or fill or a project where a structure is to be built within the zone defined as *Waters of the United States* will probably require a permit.

To reduce the delays that would result from processing a permit for each streambank protection project, the Corps of Engineers has issued a nationwide permit. The

Regulatory Functions Branch of the Corps of Engineers District having jurisdiction over the stream in which a project is to be built should be contacted to determine whether the project is covered by the nationwide permit. (The addresses and telephone numbers of Corps of Engineers Districts are listed on page 55 of this pamphlet; a map is provided on page 57 that can be used to determine in which district a particular project is located.) If the proposed project is covered by this permit, the landowner or local government will be advised in writing and construction can begin. If the project is not covered by the nationwide permit, the Regulatory Functions Branch will advise the permit applicant that he must apply for either a regional or individual permit.

Regional permits are similar to the nationwide permit but are limited to specific areas. The Regulatory Functions Branch may or may not require that the landowner or local government supply information related to the proposed project before construction is authorized under a regional permit. In either case the Regulatory Functions Branch will advise the applicant in writing whether the proposed project is covered by this type of permit.

If the proposed project requires an individual permit, an application on Engineer Form 4345 must be submitted (see pages 58 and 59). Form 4345 can be obtained from the Regulatory Functions Branch along with pamphlet EP 1145-2-1, *U.S. Army Corps of Engineers Permit Program, A Guide for Applicants*, which describes the application procedure for an individual permit. The form should be filled out completely and accurately and submitted to the Regulatory Functions Branch along with a map showing the location of the project and a good quality, easily reproducible drawing showing the important features of the method proposed to protect the streambank (see page 60). Each application is then evaluated to determine the probable impact that the project will have on the public interest. During the evaluation, a public notice is prepared and circulated for comment to the Environmental Protection Agency, the U.S. Fish and Wildlife Service, and other appropriate Federal and state agencies and interested individuals. If there are no objections, a permit will be issued in writing usually within 60 days after a completed application is received.

Objections to the project that are received in response to the public notice will be discussed with the applicant by personnel of the Regulatory Functions Branch. Possibly, the proposed design may only have to be slightly modified to eliminate the objectionable feature. On the other hand, a completely new design may be needed. Regardless, an applicant should never begin work that requires a Federal permit before official authorization is received.

All states require a water quality certification stating that a proposed project will not violate the water quality standards of that state. The Regulatory Functions Branch can advise the landowner or local government as to which state agencies should be contacted for the water quality certification or for other certifications that are required.

Step 7

CONSTRUCT THE PROJECT

When all required permits are approved construction may begin. If the landowner or local government is handling the construction, then timeliness, efficiency, and safety are the keywords — timeliness in constructing the project when the water is low and the bank is dry; efficiency in arranging for the availability of materials, equipment, and manpower to reduce any loss of working time; and proper safety considerations to minimize the chance of accidents.

Several common sense safety precautions should be followed:

- ☐ Safe access and working conditions must be maintained in the construction area.
- ☐ Someone trained in first aid techniques should be on site during all phases of

construction; an adequate stock of first aid supplies should be available.

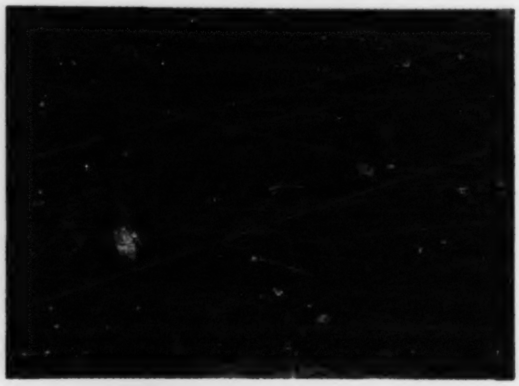
- ☐ All workmen should be physically able to undertake the effort required. No one should take unnecessary risks such as working in or near deep water without a life preserver.
- ☐ Protective clothing, such as safety shoes, gloves, goggles, and hard hats should be worn by all workmen during any type of activity requiring protection.
- ☐ Construction materials should be stored in an orderly manner on a solid, level surface.
- ☐ Waste materials should be removed from the work area regularly and disposed of properly.

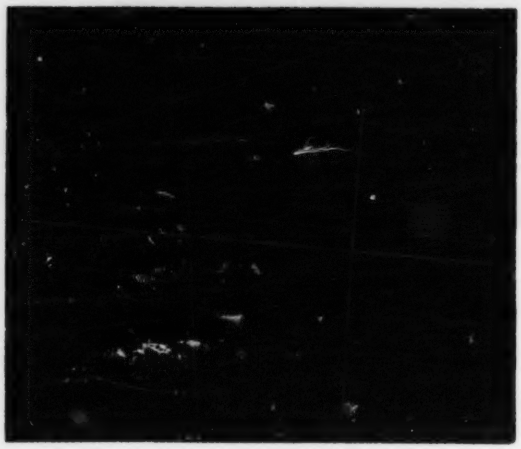
If a contractor will be hired to construct the project, competitive bids should be taken to insure obtaining quality work at the lowest price. Another factor to consider in selecting a contractor other than cost is experience. If the contractor has not previously constructed streambank protection works, he may have difficulty completing the project because of inexperience or underestimating the job. When a landowner or local government enters into an agreement with a contractor, the contract should clearly state the responsibilities of both owner and contractor. The contract should indicate exactly what will be built, how much material will be used, the beginning and ending dates of the construction period, and cost.

Site access is an essential element of preconstruction preparation.

ABOVE: An application for a Corps permit to build a streambank protection project must be submitted and approved before construction can begin.

BELOW: Local landowners begin construction of a used-tire revetment.

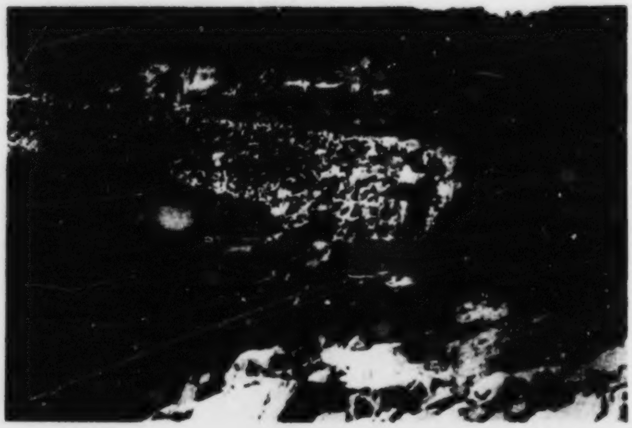




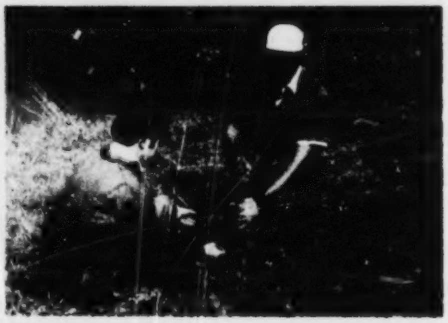
Step 8

INSPECT AND MAINTAIN THE PROJECT

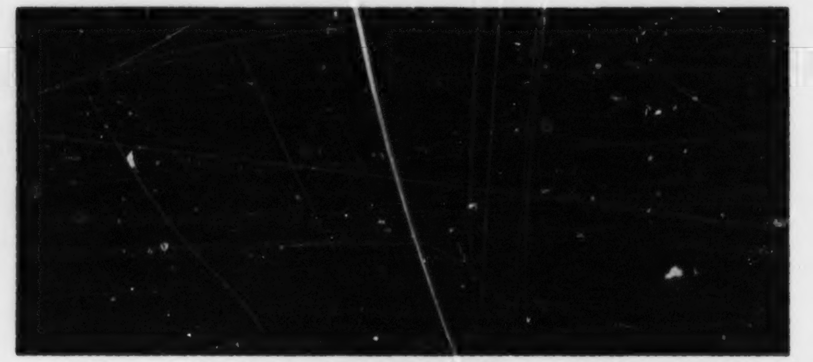
A streambank protection project will generally require some maintenance if the project is expected to protect the bank on a long-term basis. Periodic inspections should begin soon after construction is completed. Early detection and proper maintenance of a developing problem will not only avoid needless expense and property loss but could also eliminate a potential safety hazard.



ABOVE: Landowners and local government officials should periodically inspect completed projects to determine if any maintenance is needed.



Surface erosion can be monitored by placing a row of treated wooden stakes from the toe to the top of a bank.



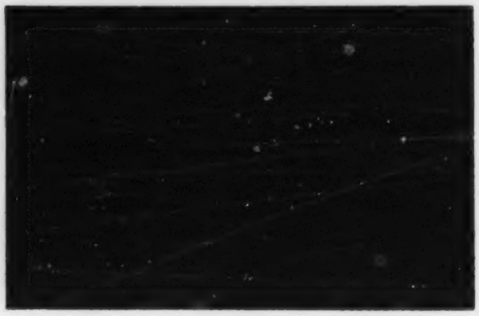
RIGHT: A plumbed rod driven at least 8 feet into a bank can be used to determine if bank movement is occurring.

Each inspection or maintenance activity should be well documented with dated photographs and sketches. For example, a gradual loss of vegetation or stone riprap may not be readily apparent during an inspection visit; however, comparison of photographs or sketches made over several visits may indicate that a problem is slowly developing.

Streambank surface erosion can be monitored by placing a row of treated wooden stakes (or metal rods) from the toe to the top of the bank. This simple method can be implemented by first driving stakes at the toe and top of the bank and drawing a taut string line between the stakes. Other stakes are then driven at regular intervals along the line. After the stakes are in place the bank should be visited frequently to determine if the bank is eroding around the stakes or if one or more of the stakes are missing entirely; either condition would indicate that active bank erosion is in progress.

A plumbed rod driven at least 8 feet into a bank can be used to determine if the bank is unstable. The rod should be plumbed with a carpenter's level as the rod is driven into the bank. If future checks indicate that the rod is tilting out of plumb, then bank movement is occurring which may signal that problems are ahead.

Once a need for maintenance is identified, more frequent inspection visits should be made until the necessary steps can be taken to correct the problem. If no maintenance of the streambank protection works is required or anticipated, then an inspection during the summer or fall low-water season and after each high-water period is probably sufficient to ensure that no serious problems develop without the knowledge of the landowner or local government.



Two Case Histories

EXAMPLE 1. By carefully following Steps 1-8 of the Plan of Action suggested above, a streambank protection project will have a better chance of effectively doing the job that it was designed to do as opposed to the builder taking a "hit or miss" approach and hoping for the best. As an example of the need for a well-developed plan of action, consider Farmer Green, who has property fronting an eroding bank. Green inspects his bank and finds erosion occurring in several areas. Not bothering to talk with his neighbors about the problem or seeking technical or financial assistance, Green decides to protect the eroding streambank with automobile bodies that he can purchase locally at a nominal price. During the summer, Farmer Green randomly dumps bodies on the eroding banks without chaining the bodies together or attempting to tie them into the bank. The scene is now set for a real problem. During the next spring, record rainfall over the upstream watershed causes flash flooding. The automobile bodies are scattered for several miles downstream along the bank and in overbank areas. Many of the bodies collide with bridge piers and docks as they drift downstream. As a result, Green is sued for damages by both landowners and the county government. In addition, the Regulatory Functions Branch of the Corps of Engineers District having jurisdiction over the waterway in which Green dumped the bodies, informs him that he is in violation of Federal laws having fines up to $25,000 per day of violation and imprisonment up to one year; also, he may be in violation of state water pollution laws. Clearly, Green's approach to bank protection was not properly planned.

EXAMPLE 2. Consider the same situation as described above except that Farmer Green follows this pamphlet's plan of action. After studying Understanding Streambank Erosion and Failure, page 7, he concludes that his bank erosion problem is due to passing stream currents during flood flow. After some consideration, he decides that he will try to save the bank by following the suggested plan of action as closely as possible. He discusses the problem with his upstream and downstream neighbors who have similar conditions along their property fronting the stream. Collectively, they decide to contact the county's SCS office and request that the district conservationist inspect the eroding banks. The conservationist determines that there are ten eroding sections fronting the bankline of the landowners, five of which should be considered as serious and five not so serious. In four of the seriously eroded areas the conservationist suggests dumping concrete rubble that may be available from a nearby highway construction project. At the fifth seriously eroding area, the bank is rapidly failing on one side of the stream while a point bar is building up on the other bank. The net result is a continuing exchange of productive farmland for a nonproductive sandbar. The conservationist recommends construction of several post and wire fence dikes extending from the existing eroding bank into midstream. These structures will encourage sediment deposition (and build up the eroding bank) while forcing the current against the sandbar. This type of fencing could easily be erected during a low-water period using group manpower and available farm equipment. Finally, he recommends planting willows along the less seriously eroded banks. The conservationist also helps the landowners apply for financial assistance from the ASCS and to secure a sufficient number of rooted willows to plant on the five less seriously eroded banks. The conservationist also arranges to obtain a limited number of a superior willow selection from an SCS Plant Materials Center for evaluation on one of the eroded banks.

After contacting the State Highway Department through a state legislator, the landowners are advised that the concrete rubble is available at no cost. The highway construction contractor agrees to break the pavement up into pieces small enough so that the rubble can be handled with a front-end loader. The County Highway Department agrees to remove the rubble from the construction right-of-way and to dump the material on the four seriously eroding banks providing the landowners will provide the necessary access. The ASCS advises the group that $1,000 can be made available for construction of the fence dikes.

At this point, the equipment and resources needed to construct the project are in place. Farmer Green and his neighbors and the SCS conservationist then develop a project plan that includes the following major work items:

- ☐ Prepare a legal agreement to be signed by the landowners releasing them from apparent damages to each other's property as a result of the streambank protection project.
- ☐ Draw up diagrams and maps showing how the bank will be protected at each of the ten locations.
- ☐ Lay out access routes to the five seriously eroding banks.
- ☐ Collectively agree to provide the manpower necessary to construct the fence and plant the willow shoots as soon as possible after the spring high water has gone down.
- ☐ Request that the County Highway Department dump the rubble as soon as access routes can be made available.

After the project plan is completed, the landowners in consultation with the SCS conservationist determine that no apparent adverse environmental impacts will result because of the proposed construction. The next step is to contact the Regulatory Functions Branch of the Corps of Engineers District in which the project is to be constructed. The Regulatory Functions Branch provides the landowners with Engineer Form 4345 (Permit Application), pamphlet EP 1144-2-1, and information on how to apply for water quality certification from the State Pollution Control Agency. The landowners complete and submit Form 4345 and the state form for a water quality certification; 60 days later both the approved permit and water quality certification have been received and construction can proceed. After the project is completed Farmer Green and his neighbors agree to periodically inspect the parts of the project fronting their property and to report any problems to the other landowners.

CONCLUSION. The two examples discussed above probably represent the extremes in landowner and local government streambank protection projects — one project where nothing was done right and the other where the project was well-planned and there were no problems with resources or permits — a model project. The majority of projects will fall somewhere in between these two extremes; however, all efforts should be initiated with the goal of constructing a model project.

Streambank Protection

There are five general approaches to be considered when dealing with a streambank erosion or failure problem:

- —Relocate endangered assets
- —Implement effective land use management practices
- —Reroute the stream channel away from the problem area
- —Remove streamflow obstructions
- —Plan, construct, and maintain a project that will provide the needed streambank protection

The decision to deal with the problem or "let nature take its course" is part of the planning process. If the landowner or local government decides to try to alleviate the problem caused by a distressed bank condition, then one or more of the five approaches discussed in this section may be applicable.

RELOCATE ENDANGERED ASSETS

For problem areas where streambank erosion or failure must be halted, relocation may not be a practical consideration. However, if the bank can be allowed to erode or fail without any serious consequences other than loss of a structure, road, or utility line, then relocation of these assets away from the problem area may be a viable solution. If relocation is feasible, the key factors that must be considered are the bank recession rate and the available relocation distance. If [illegible] bank has receded at an average rate of 10 feet per year for the past 5 years and a road can only be moved 20 feet, relocation is not a logical consideration; however if the bank has receded at an average rate of 3 inches per year for the past 50 years, then relocation would be a much more attractive solution to the distressed bank problem. Recession rates can often be determined from dated photographs, surveys, or plat maps. Also, information can be obtained from county land records, local public and historical libraries, national and state archives (contact National Archives and Records Service, General Services Administration, Washington, DC 20408, phone 202-523-3236), the ASCS (contact ASCS Aerial Photography Field Office, P. O. Box 30010, Salt Lake City, UT 84130, phone 801-524-5856), and the U.S. Geological Survey (see address on page 21). Relocation without the benefit of any recession rate information is risky at best.

IMPLEMENT EFFECTIVE LAND USE MANAGEMENT PRACTICES

Landowners and local governments can reduce the probability of streambank erosion or failure by maintaining or implementing effective land use management practices. These practices include:

- —Protection of existing vegetation along streambanks
- —Regulation of irrigation near streambanks
- —Rerouting overbank drainage
- —Control of rainfall runoff
- —Minimizing load on top of streambanks

Relocation of this home may be more cost-effective than protecting the bank.

The protection provided by existing vegetation on streambank slopes and in greenbelts adjacent to streambanks is often the key factor that prevents development of a distressed bank condition. Several basic land use management practices should be observed to protect the vegetation:

Clearing of a greenbelt adjacent to the top of a streambank often leads to severe erosion. Note natural greenbelt in background.

RIGHT: Selective tree removal can eliminate problems caused by large trees toppling into a stream. The chain around the trunk of the tree is tied off to another tree further up the bank slope. After the tree has been cut down, the chain can be used to drag the tree out of the floodplain so it will not become floating debris or contribute to a log jam during the next floodflow.

BELOW: Animals should not be allowed to strip and trample protective vegetation on streambanks.

a. Greenbelts should not be clearcut to top bank to provide more land for cultivation or to provide a better view. The greenbelt prevents overuse of the top bank area by man, animals, and machinery. The belt also retards rainfall runoff down the bank slope and provides a root system that binds soil particles together.

b. In contrast to clearcutting a greenbelt, trees may need to be selectively removed or trimmed to promote grass and brush growth on top bank and on the streambank slope.

c. Many distressed streambank problems are caused by trees that are gradually undermined by flowing water and topple into the stream. Fallen trees can cause two problems: they may divert the streamflow into a bank or their root mass may leave a large, exposed hole susceptible to erosion. This problem can be minimized by removal of those trees that are likely to fall into the stream.

d. People, vehicles, and grazing animals should be kept off of streambank slopes to prevent vegetation from being stripped or trampled. If access between the top and toe of the bank is needed, steps or a ramp should be constructed. fencing can be erected along the top of the bank to keep vehicles and grazing animals back from the bank.

Irrigation near a streambank should be regulated such that protective vegetation and cultivated plants receive their needed amounts of water. On the other hand, irrigation should not be so excessive that the bank becomes saturated. This condition may lead to swelling of clay or increased groundwater pressure from within the bank, both of which may lead to bank failure. Another type of irrigation problem can develop during the summer months when stream levels are low. Because crop irrigation is most intensive during this period, seepage can develop on the bank face. As seepage occurs, soil particles on the bank surface may be forced loose. The resulting downslope movement of seepage water and loosened soil particles can further erode the bank.

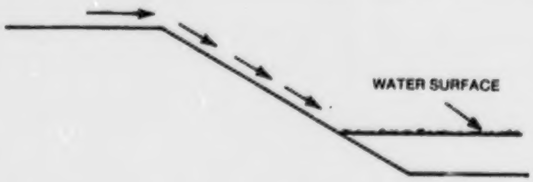
Unless effectively controlled, overbank drainage can cause sheet and rill erosion on streambank slopes. Overbank flow can be intercepted and rerouted away from the top of a bank by ditching or a diversion dike. The ditch or dike should be laid out along top bank to a location where the water can be safely discharged into the stream without causing soil erosion (such as through a lined ditch or pipe). Runoff should not be allowed to pond behind a dike and drain through the bank face as groundwater seepage because the bank may become saturated and fail.

Good soil conservation practices such as contour farming, terracing, strip cropping, controlled grazing, and construction of farm ponds can play a major role in controlling local rainfall runoff. When such conservation practices are widely and intensively used, they can change flow conditions so that more of the runoff is held in fields and ponds or at least delayed such that peak flood flows passing a streambank are reduced. With flood peaks reduced, the potential for bank erosion and failure is decreased. Urban development can also change rainfall runoff conditions but not in the beneficial manner of effective soil conservation practices. Buildings, highways, and parking lots cover large areas that were once available for rainfall infiltration before urbanization. The reduction of natural surface area and the construction of efficient stormwater sewer systems in upstream urbanized areas can accelerate rainfall runoff and result in greater-than-normal downstream flood flows. Zoning ordinances to manage urban growth and regulations to control runoff rates can help to alleviate downstream flood problems.

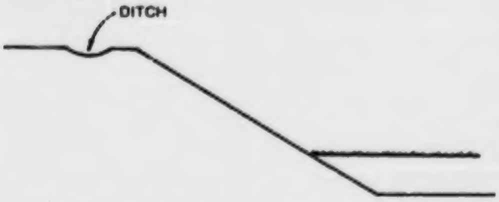
Excessive load on the top of some banks may lead to failure. Since a detailed analysis by an engineer is required to determine how much load can be safely placed on top of a bank, the best policy is not to construct buildings near the top of a bank and to keep heavy vehicles away from the bank.

REROUTE THE STREAM

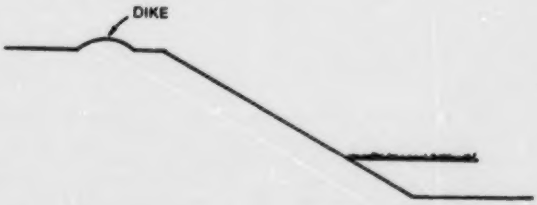
If streamflow along the outside bank of a bend (the cut bank) is the principal reason that a landowner or local government finds a bank in a distressed condition, then relocation of the channel can be an economical alternative to more costly approaches to protect the bank. Channel relocation is usually accomplished by cutting a pilot channel from a point upstream of the distressed bank to a point downstream from the bank. Because the slope of the pilot channel is steeper than the natural channel, the stream will start to flow through the pilot channel. This flow will erode soil from the banks and bed of the pilot channel, thus increasing the water carrying capacity of the new channel. Eventually the pilot channel will capture the



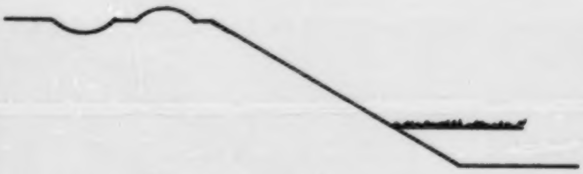
A. Uncontrolled overbank drainage can cause surface erosion and the formation of gullies on an improperly protected bank.



B. A ditch dug along the top of a bank can intercept and reroute drainage.

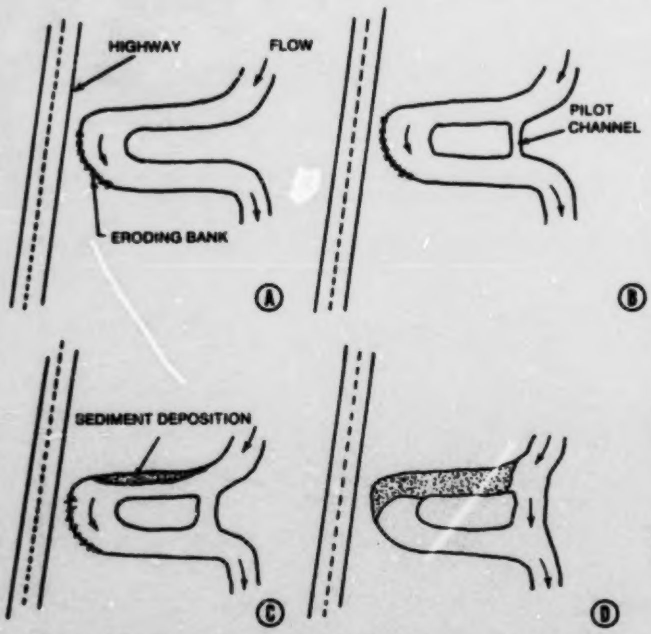


C. A diversion dike can also be used to intercept and reroute drainage.



D. Combination ditch and dike (constructed from material excavated from ditch).

Methods to control overbank drainage.



Protection of eroding bank by rerouting the stream. A. Eroding bank threatens highway. B. Pilot channel is excavated. C. Pilot channel begins to capture streamflow; some sediment deposition occurs in the natural channel. D. Pilot channel has captured the streamflow; water movement through the natural channel is now blocked by sediment deposition and bank erosion is stopped. See "Caution" in text.

Trees undermined by passing streamflow can deflect current against opposite bank. Arrow indicates direction of deflected streamflow.

streamflow as the channel enlarges and as the slower water movement through the natural channel is blocked by sediment deposition. Although excavating a pilot channel with heavy equipment or explosives may provide a quick and relatively economical method for keeping streamflow away from an eroding bank, this action may cause serious future problems. Shortening the length of a channel can upset the natural balance of a stream. As a consequence, bank erosion may result upstream from the pilot channel and flooding downstream. *CAUTION: prior to developing a plan to protect a streambank by excavation of a pilot channel, the Corps of Engineers or the SCS should be contacted for professional guidance.*

REMOVE STREAMFLOW OBSTRUCTIONS

Obstructions in a stream channel can alter the flow characteristics of the stream in a manner such that bank erosion and failure may occur. Typical problems are:

a. A tree undermined by passing flow can fall into the stream and deflect the current against a bank.

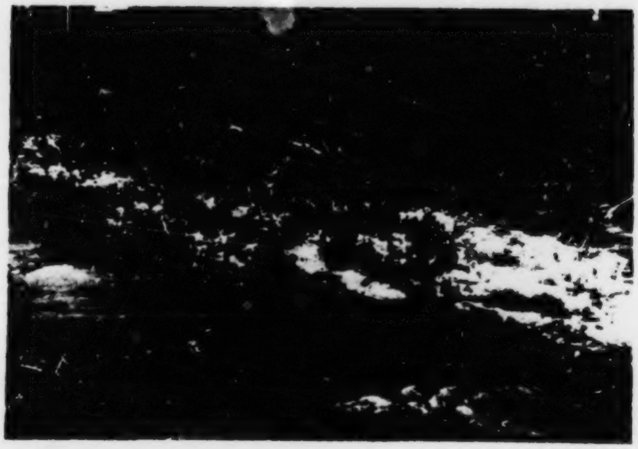
b. Log jams can develop at constrictions such as a bridge or a narrow reach of the stream or where one or more trees have fallen into the stream and block the travel of logs and debris floating downstream.

c. Midchannel sand and gravel bars form when the stream velocity decreases to a point where sediments can no longer be carried by the water. As a bar forms the current may be shifted against a bank causing erosion.

d. As water passing through the inside of a bend slows down, the sediments moving with the current flow settle out and start building up a point bar. As the bar builds up it can deflect the stream current against the bank across from the point bar.

Solutions for these problems are discussed below; however, landowners and local governments should be aware that implementing these solutions may provide only

Bank erosion may occur as a stream attempts to flank a log jam.

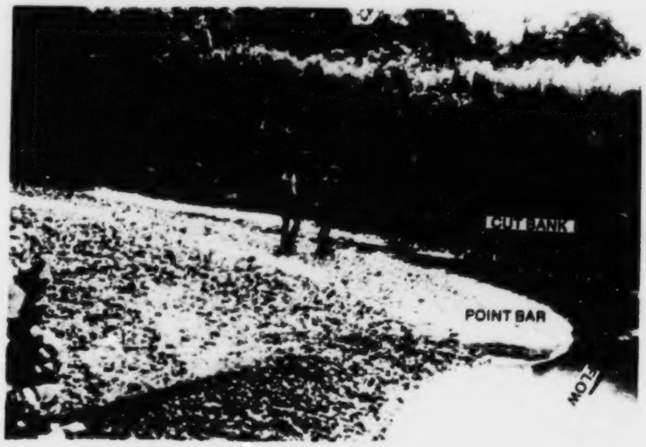


Formation of a midchannel sand and gravel bar forces current against the far bank. Tilt of tree stems indicates that severe erosion is occurring around the roots.

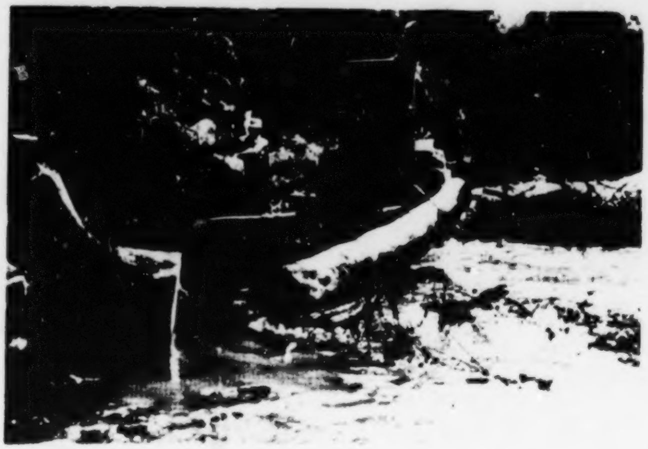
temporary relief unless used in conjunction with permanent bank protection works. For instance, removal of a point bar may move erosive currents away from the cut bank, however the point bar will probably build up again. When this occurs the cut bank will again come under attack and suffer erosion unless measures have been implemented to protect the bank with a revetment or dikes.

The remedy for fallen trees and log jams is twofold: saws and safety. Due to the unstable nature of fallen trees and log jams in a stream and the potential danger of injury when using high speed chain saws, rigid safety practices must be enforced while clearing a channel. Once a log is free, it should be removed far enough from the channel such that it cannot be refloated during high water and contribute to another log jam.

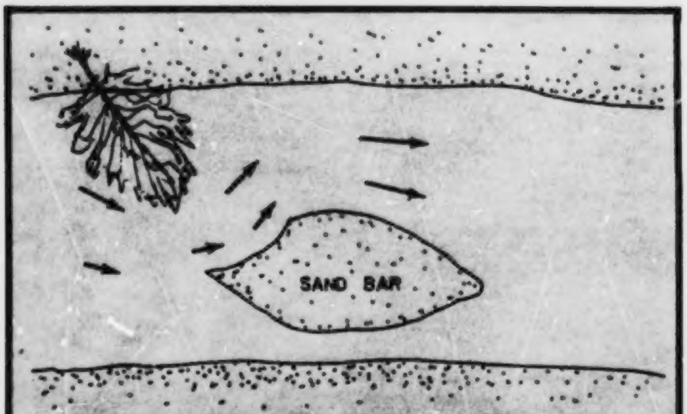
Because of the large volume of sand and gravel involved, the landowner or local government probably cannot remove a mid-channel bar or point bar. The alternative is to let the stream do the work by using the following procedures. If there are tall trees growing on the bar, they should be removed with a tractor and a block and tackle, if necessary. Always remove as much of each tree's root mass as possible. The extensive root system of large trees hold the sand and gravel in place on the bar. If the tree is too large to pull out, cut it down at ground level. Smaller shrubs need not be removed at first since their root systems are usually shallow.



Point bar deflects stream current against cut bank.



Log being removed from channel.



Large tree used as current deflector to erode midchannel bar.

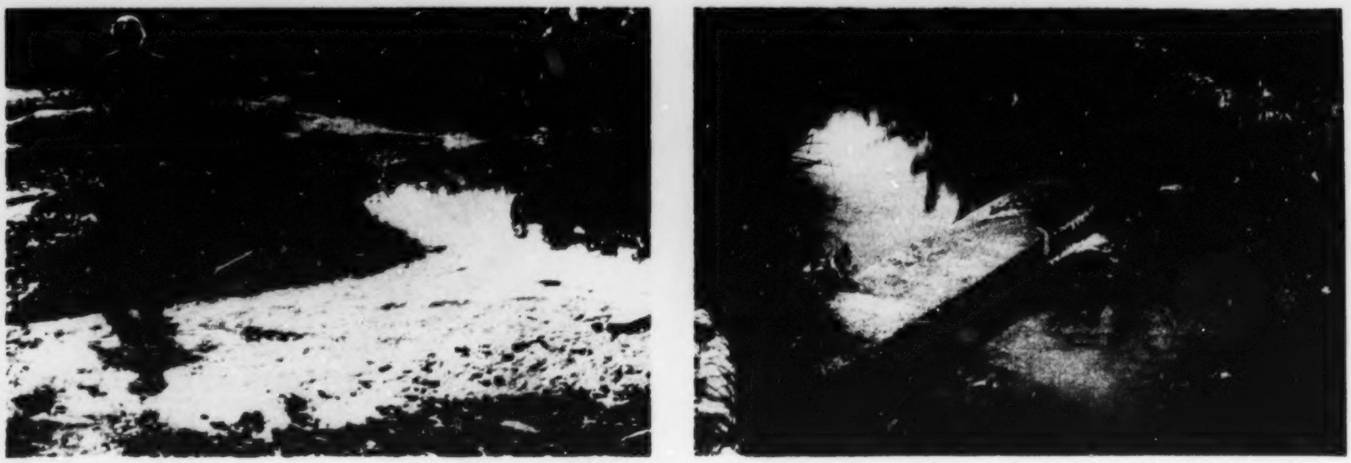
If later observations indicate that the shrubs are preventing the bar from eroding, then they will have to be removed. Next, dig one or more pilot channels through the bar. The pilot channels can be dug with hand tools if trenching equipment is not available or if the bar is not accessible to machinery. Locate the channels at such an angle that a rapid current is diverted into the trench. This rapid current is needed to erode the bar. If the bar is large, several pilot channels may have to be dug. Any large stones or leaf debris should be raked off the sides of the bar. This will increase the current flow along the edges of the bar and promote erosion. If the bar is not removed by flow through the pilot channels, a current deflector can be used. The deflector consists of a brush pile or fallen tree secured at a point upstream from the bar. The current deflector should be positioned to divert the stream current against the bar. If the bar is large, several current deflectors may be needed to divert the current into the bar at several points.

STREAMBANK PROTECTION METHODS

Many streambank protection methods have been tried over past years, some being very successful and some not so successful. Several of these methods are not suitable for landowners and local governments because of heavy equipment requirements, costly construction materials, and the need for extensive financial and professional assistance. Further, some approaches to streambank protection may significantly alter the channel such as the formation of a scour hole adjacent to a project; thus, allowances must be made in project design plans to accomodate anticipated channel modifications. In spite of these constraints, several approaches to bank protection, *(both singularly and in combination)*, are realistically within the resources of local interests. Some of the more feasible methods are: (1) bed scour control, (2) vegetation, (3) bank shaping, (4) surface soil stabilizers, (5) riprap, (6) rubble, (7) gabions and wire mattresses, (8) sacks, (9) blocks, (10) used-tires, (11) fences, (12) Kellner jacks, (13) bulkheads, and (14) dikes.

BED SCOUR CONTROL. The streambed

Pilot channel eroding point bar (left). Concrete check dam (right).

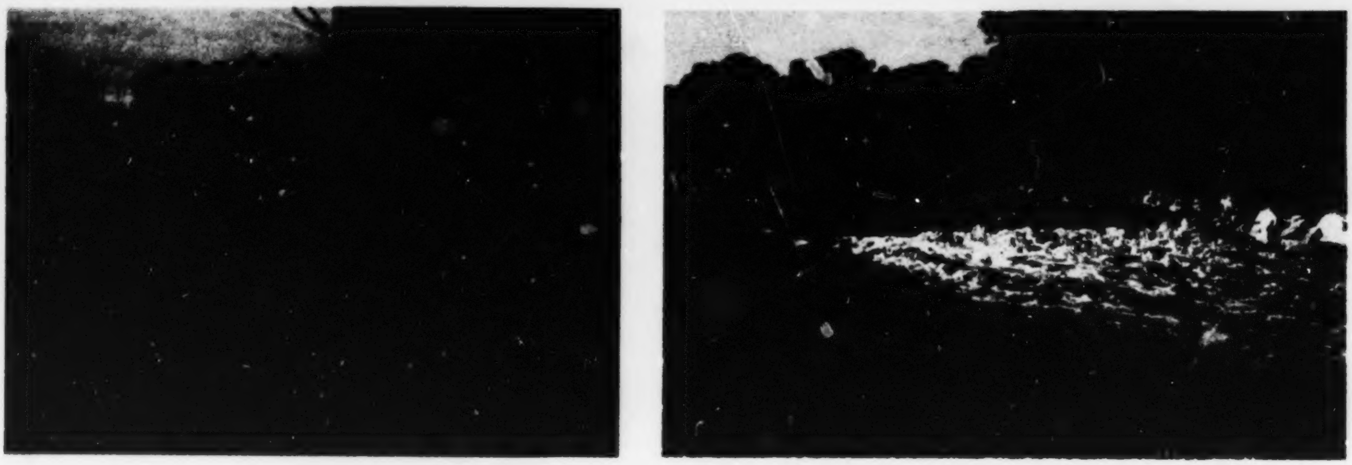


acts as a foundation for its banks. If streamflow scours out the bed and in the process erodes the bank toe, then the upper bank may no longer have sufficient support; bank failure can follow. Streams experiencing active bed scour can be identified by the presence of small waterfalls or a short reach of rough water in an otherwise tranquil stream (often called headcutting). Two methods are commonly used to control bed scour: check dams and lining the channel with erosion resistant materials.

A check dam should be placed bank to bank across the scouring channel bed and located downstream from the rough water or waterfall. (NOTE: Check dams can also be placed upstream from the waterfall or rough water to intercept the headcut; however, this solution should not be considered without the benefit of professional assistance.) The net effect will be to reduce the stream velocity and to encourage sediment deposition which will build up the scoured bed. Check dams can be constructed from stone, concrete, sand-cement bags, treated timber, metal, etc. The toe of the check dam should be well protected to prevent the structure from being undermined. Further, the ends of the dam should be rooted into the banks so the structure cannot be flanked. Streambanks immediately downstream from a check dam sometimes show a tendency to erode. These banks should be watched after the dam is completed. Check dam construction can be very expensive; thus, in most cases this constraint will limit landowners and local governments to work on small streams. Further, these dams can affect the overall balance of a stream and its tributaries. Professional assistance should be sought before one or a series of dams are placed in a stream.

Another approach to controlling channel bed scour is lining the bed and lower bank with erosion resistant materials. Suitable materials are stone, rubble, sand-cement bags, blocks, or establishing a healthy stand of grass tolerant to inundation. Also, a filter may be required (see Glossary). The cost for constructing a lined channel can be prohibitive if the reach of a stream that is experiencing bed scour is long or the bed is wide.

VEGETATION. Of all the approaches available to landowners and local governments for protecting a streambank, vegetation is probably the most commonly used method because it is relatively easy to establish and maintain, is visually attractive, and is the only streambank protection method that can repair itself when damaged. Below a stream's waterline, vegetation can effectively protect a bank in two ways. First, the root system helps to hold the soil together and increases overall bank stability by forming a binding network. Second, the exposed stalks, stems, branches and foliage provide resistance to the streamflow, causing the flow to lose energy by deforming the plants rather than by removing soil particles. Above the waterline, vegetation

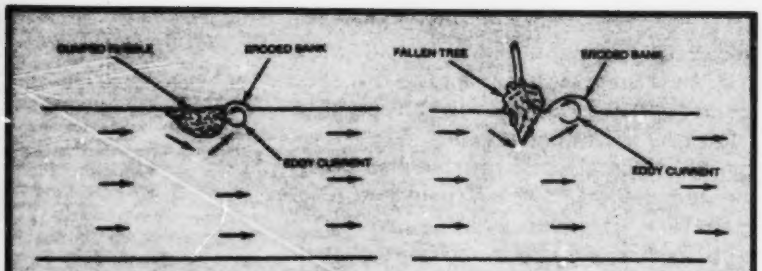


The bed and lower bank of this channel were lined with manufactured precast concrete blocks to retard active bed scour. Openings in the blocks allow grass to grow through (left). Properly selected grass species can provide effective streambank protection (right).

prevents surface erosion by absorbing the impact of falling raindrops and reducing the velocity of overbank drainage flow and rainfall runoff. Further, vegetation takes water from the soil providing additional capacity for infiltration and may improve bank stability by water withdrawal.

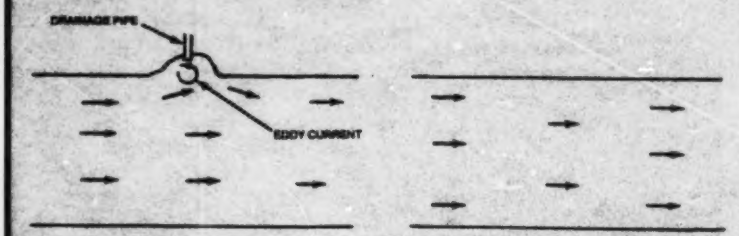
Vegetation is generally divided into two broad categories: grasses and woody plants (trees and shrubs). The grasses are less costly to plant on an eroding bank above the toe and require a shorter period of time to become established. Woody plants offer greater protection against erosion because of their more extensive root systems; however, under some conditions the weight of the plant will offset the advantage of the root system. On very high banks, tree root systems do not always penetrate to the toe of the bank. If the toe becomes eroded, the weight of the tree and its root mass may cause a bank failure.

The major factor affecting species selection is the length of time required for the plants to become established on the slope. Species selection should also be based on compatibility with the soil, air temperature ranges, total rainfall, distribution of rainfall, bank slope, and the ability of the soil to store water for plant growth during dry periods. For sections of a streambank where scour is a problem, woody plants established at the toe of the slope and grass above the toe have proven to be good protection. For assistance with species selection, landowners and local governments should contact the USDA Soil Conservation Service, USDA Forest Service, county agricultural extension services, soil and water conservation districts, as well as other experts. Information needed to contact the SCS Plant Materials Centers is provided on pages 53-54.



A. Protrusion of dumped rubble into the streamflow causes an eddy current to form.

B. Crown of a fallen tree sets up an eddy current.



C. Indentation in the bankline due to an improperly constructed drainage pipe outfall results in eddy current development.

D. Rehabilitation of a rough zone allows the bank to conform to the passing streamflow and minimizes bank erosion.

Rough zones along a streambank may cause erosion due to eddy current circulation.

Grass can be planted by hand seeding, sodding, sprigging, or by mechanical broadcasting of mulches consisting of seed, fertilizer, and other organic mixtures. Several commercial manufacturers now market economical erosion control matting that will hold the seed and soil in place until new vegetation can become established. The matting is generally installed by hand and secured to the bank with stakes or staples. If livestock graze near a bank where plantings have been made to prevent erosion, then a fence should be placed along top bank. If the livestock require access to the stream for watering or crossing, gates should be placed in the fence at locations where the cattle will do the least amount of damage to the planted bank; additionally, crossings should be fenced.

BANK SHAPING. A properly shaped streambank should be smooth enough to prevent *rough zones* along the bankline from setting up eddy currents that may severely erode the bank. These zones are caused by protrusions or indentations in the bank line. Such irregularities should be removed by smoothing the bank surface. All areas that are exposed or stripped of vegetation during rehabilitation of a rough zone should be protected with vegetation or some other type of streambank protection. The reader should note that a series of protrusions (or dikes) may sometimes be successfully used for streambank protection; however, unless properly designed, there is a danger of creating the undesirable rough zones just discussed. A later section in this pamphlet describes the proper placement of dikes.

Another method that can be used to stabilize a bank is shaping the bank (more commonly called laying the bank back) to a slope less than the maximum slope at which the bank can stand without any danger of failing. Determination of how far a bank must be laid back to satisfy this requirement is a very complex problem. The tradeoff is to ensure that the bank is laid back far enough to minimize the chances of failure, but on the other hand not so far that unnecessary earthwork is done. If this method appears to be a feasible approach, then professional assistance should be sought to develop a sound estimate for an acceptable slope steepness.

SURFACE SOIL STABILIZERS. Three surface soil stabilization methods have been successfully used for streambank protection: (1) sand-cement blankets, (2) clay-lime-cement blankets, and (3) mulches.

A sand-cement blanket with 8 to 15 percent cement is an economical and effective streambank protection method for use in areas where vegetation is difficult to establish and the bank material is predominately sand. The sand can be mixed with cement by hand or mechanically to a depth of at least 4 inches. The mixture should then be wet down and allowed to set up. This method has the advantage of low cost. However, there are three major disadvantages: impermeability, low strength, and susceptibility to temperature variations. If the bank behind the blanket becomes saturated and cannot drain, failure may occur. Also, because a sand-cement blanket is relatively brittle, very little if any traffic (vehicular, pedestrian, or livestock) can be sustained without cracking the thin protective veneer. In northern climates the blanket can break up during freeze-thaw cycles.

If the streambank soil is mostly clay, lime must first be mixed with the soil to make the tiny clay particles form *clods*. After a suitable curing period, cement is then mixed with the soil and wet down. The bank is then compacted by rolling a rubber-tired vehicle over the surface. This operation strengthens the soil against erosion. There are no firm guidelines on the percentage of lime to be mixed with the clay, the curing time, the percentage of cement to be mixed with the clay-lime clods, or the number of times the rubber-tired vehicle must pass over the bank surface to bring it to a condition of maximum erosion resistance. Professional assistance should be sought if this type of bank protection is considered.

Mulches composed of straw, hay, and wood chips are commonly used to stabilize exposed soils prior to seeding for long term vegetation growth. In addition to functioning as an intermediate stabilization measure, mulches, when applied during permanent seeding, also aid in the germination process by conserving moisture and absorbing the impact of falling raindrops.

RIPRAP. Stone riprap is natural rock dumped or hand placed on a streambank to prevent erosion. Three general approaches are used:

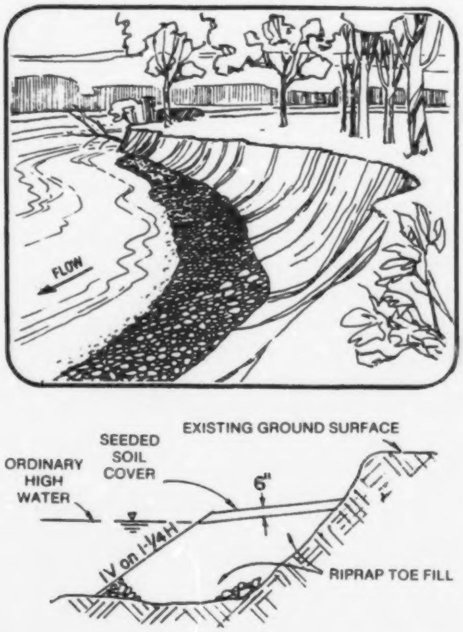
- Riprap placed along the toe of a bank to minimize scour
- A riprap blanket laid over a bank slope to prevent erosion
- A windrow of riprap stockpiled on top of or buried in an eroding bank to stop advancing erosion

These three approaches are discussed below.

When the toe of a bank is scoured out, support for the upper bank is lost. As a result, the upper bank may fail. Stabilization of a bank toe with riprap in conjunction

Soil-cement blanket.

(Photo courtesy of Portland Cement Association)



Riprap is an effective method to control toe scour. A drawing of a typical toe is shown in the lower view.

with some other form of protection on the upper bank such as vegetation offers an effective approach to bank protection if toe scour is the major problem.

Riprap blankets can be used to protect streambanks in areas where quality stone is economically available. A blanket is relatively flexible and can conform to minor changes in bank shape due to settlement or scour. In addition, construction of a riprap blanket is not complicated, no special equipment is necessary, and minor damages can be repaired by placement of more stone. For these reasons, riprap blankets are widely used as protection for an entire bank face or in some cases the portion of the bank below the high water mark. Several factors should be considered in properly designing a riprap blanket:

- ☐ What shape and weight of stones will be stable in the streamflow?
- ☐ What blanket thickness is required?
- ☐ Is a filter (see Glossary) needed between the bank and the blanket to allow seepage but to prevent erosion of bank soil through the blanket?
- ☐ How will the blanket be stabilized at the toe of the bank?
- ☐ How will the blanket be tied into the bank at its upstream and downstream ends?

A completed stone riprap blanket.

Block-type riprap is preferred over elongated stone for construction of a blanket because the stones fit together better. Large protruding stones should be removed from the blanket or broken up because accelerated water flow around a large stone can cause scour as well as removal of small stones adjacent to the large one. A well distributed mix of stones weighing from 20 to 200 pounds will be suitable for applications where the maximum stream velocity is less than 10 feet per second.* With this range of weights, the openings formed by the larger stones will be filled with the smaller stones in an interlocking fashion. The stone should be hard and dense and free from cracks and other defects that would tend to increase deterioration due to weathering. Professional guidance should be sought if there is any question about the quality or size of the stone.

For banks where the primary soils are silt and fine sand, a filter can be placed between the riprap blanket and the bank to prevent the loss of fine materials through the blanket but to still allow seepage. A layer of gravel and/or sand or a properly selected filter fabric is suitable as a filter. If a filter is used, technical assistance should be obtained to ensure that the filter will be properly matched with the riprap blanket and the soil.

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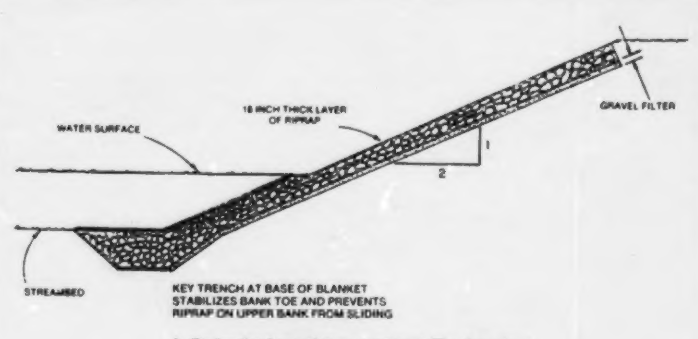
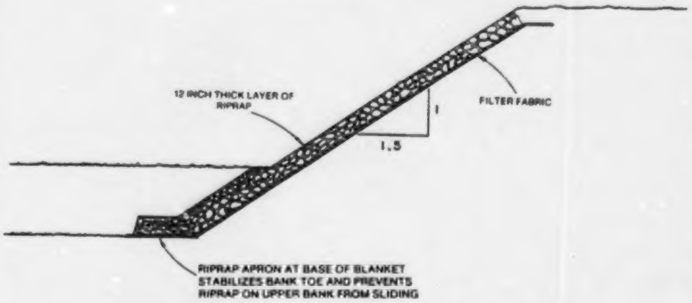
* The stream velocity can be estimated by tossing a wood chip into the flow near the bank where the riprap is to be placed and then measuring the time required for the chip to travel over a known distance. For instance, if the chip floats 100 feet downstream in 11 seconds, its velocity is 9 feet/second. The greatest velocities generally occur during flood flow, therefore, the best estimate for the maximum stream velocity would probably result from measurements made during high water periods.

The thickness of a riprap blanket should be at least 1 to 1.5 times the maximum diameter of the largest stones used in the blanket or twice the average diameter of the stones used. For most applications, a 12- to 18-inch-thick blanket is acceptable. The thickness of the blanket should be increased 50% for portions of the revetment that will be underwater at the time of placement. The recommended maximum slope steepness for dumped stone is 1 foot vertical for 2 feet horizontal. The maximum slope can be increased to 1 foot vertical for 1.5 feet horizontal for hand-placed stone. The blanket should be stabilized at its base with a key trench or apron to prevent the stone from sliding down the bank. The upstream and downstream ends of the blanket should be tied into the bank to prevent stream currents from *unravelling* the blanket. The most common method to tie into the bank is to dig a trench at the ends of the blanket. The depth of a trench should be twice the blanket thickness and the bottom width of the trench three times the thickness. Once the final plans for a riprap blanket are completed, they should be submitted for technical review to an engineer experienced in stone riprap blanket design.

In addition to using stone riprap for toe protection and for construction of a blanket, riprap can be stockpiled or buried along the top of an eroding bank as a windrow revetment. As the windrow is undercut, riprap will slide down the bank and armor the eroding area which will help to prevent further undercutting. Once the erosion is stopped, any stone that is not undercut can be salvaged and relocated on the top of another eroding bank. Care should be taken not to overload the top bank such that a failure occurs due to the weight of the riprap (see next page).

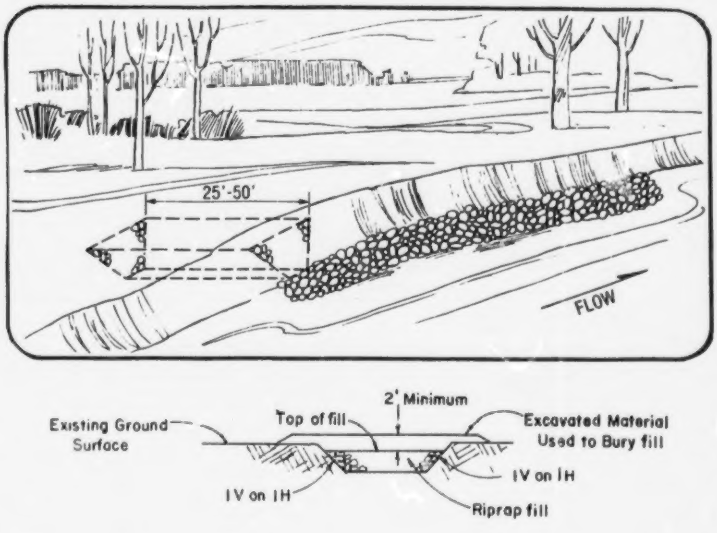

WATER SURFACE
18 INCH THICK LAYER OF RIPRAP
GRAVEL FILTER
1
2
STREAMBED
KEY TRENCH AT BASE OF BLANKET STABILIZES BANK TOE AND PREVENTS RIPRAP ON UPPER BANK FROM SLIDING

A. Design for dumped stone revetment. The slope steepness (maximum) is 1 ft vertical for 2 ft horizontal.

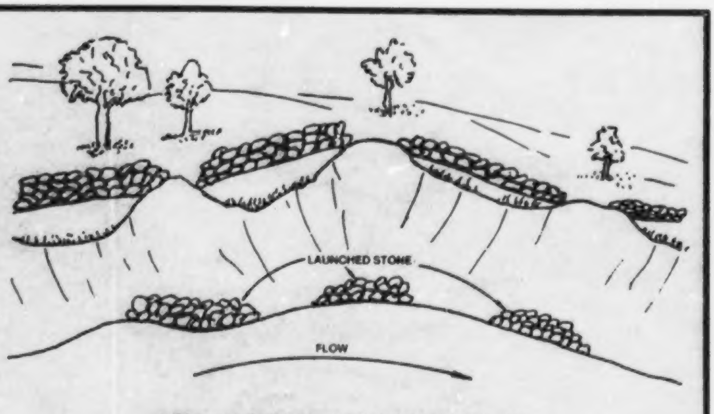

12 INCH THICK LAYER OF RIPRAP
FILTER FABRIC
1
1.5
RIPRAP APRON AT BASE OF BLANKET STABILIZES BANK TOE AND PREVENTS RIPRAP ON UPPER BANK FROM SLIDING

B. Design for hand-placed stone revetment. The slope steepness (maximum) is 1 ft vertical for 1.5 ft horizontal.

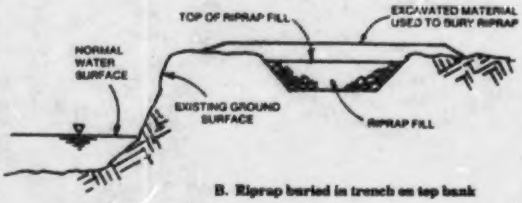
Typical stone riprap blanket designs.


25'-50'
FLOW
2' Minimum
Existing Ground Surface
Top of fill
Excavated Material Used to Bury fill
1V on 1H
1V on 1H
Riprap fill

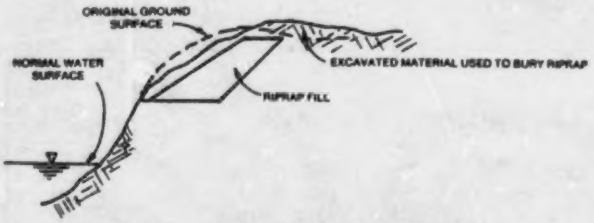
A tie-in trench should be dug into the bank at the ends of the riprap blanket to prevent the revetment from unravelling. In the example shown, the trench has been dug to the top elevation of the upstream end of the revetment; as unravelling occurs the stone slides into the eroded revetment to prevent flow behind the blanket. Under optimum construction conditions, heavy excavating equipment is available so that the trench can be dug to the elevation of he waterline or lower.



A. Riprap stockpiled on top bank. Note that some stone has been undercut and launched down the slope to protect the toe.



B. Riprap buried in trench on top bank



C. Riprap buried in notch on top bank

Windrow revetment. Caution should be exercised in working near top bank with heavy equipment.

RUBBLE. Urban renewal projects and other redevelopment efforts have made large quantities of rubble available. Although sometimes unsightly, rubble can provide an effective alternative approach to bank protection when minimal funds are available. The major problem associated with using rubble is that there is often no control over the type and size of materials dumped on an eroding bank. As a result, the rubble may offer little protection because of insufficient weight to stay in place during floodflows and in addition may pollute the stream if the dumped material is soluble in water or will rust. Some of the types of rubble suitable for dumping on an eroding bank include broken pavement, bricks, building blocks, slag, and quarry waste. Large flat slabs should be broken up into smaller pieces. Garbage, vegetation, scrap lumber, gypsum board, roofing, metal refuse, etc., should not be used under any circumstances.

GABIONS AND WIRE MATTRESSES. If available stone is not of sufficient size to stay in place during floodflow or if the bank to be protected is steep, then rock and wire in combination can provide several alternatives to stone used by itself. The more commonly used combinations are:

—Gabions

—Rock and wire mattress

—Wire mesh over stone

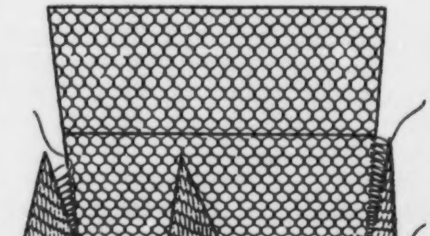
Commercially prefabricated gabions have been marketed in Europe for many years; however, this type of gabion has only been available in the United States during the past 20 years. The basic element of the gabion revetment is the cage or basket. The basket is a rectangular wire-mesh structure divided into cells. The mesh is generally galvanized steel wire.

Prior to placement of the baskets, a support apron should be laid on the bank toe extending past the foot of the gabion revetment (the apron can also be constructed out of gabion baskets). Each basket should be placed and securely wired to the apron or its neighbors and then filled with stone which should be larger than the wire mesh openings. Tie wires are often connected between opposite walls inside the cells prior to filling with stone to avoid bulging on the sides of the basket. Although gabion baskets are commercially available, they can be constructed using a wooden or metal frame.

The rock and wire mattress is closely akin to the gabion approach except that the basket is much thinner. Prefabricated baskets are commercially available; however, they can be made from locally available materials. Although the rock and wire

Rubble revetment constructed from broken pavement, concrete blocks, and house brick.

Junk dumped on an eroding bank is not only unsightly but will not provide any long-term protection.



Prefabricated commercial gabion basket.

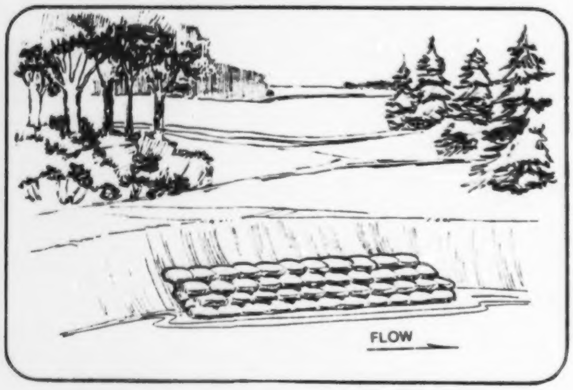
Completed gabion revetment made from prefabricated baskets. Note support apron (arrow) extending from toe of structure.

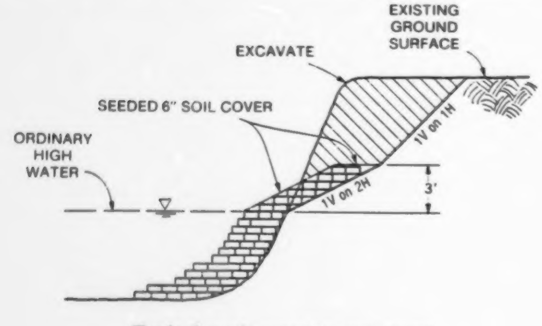
mattress is generally used as a substitute for a riprap blanket when stones of sufficient size are not available, the mattress has the added benefit of generally requiring a lesser thickness of stone than the blanket to achieve the same degree of protection. The major drawback is that a rock and wire mattress generally costs more to place than a comparable riprap blanket.

The most economical combination of rock and wire for streambank protection is simply laying wire mesh over stone. The major problem with this approach is keeping the mesh in place. One successful solution has been to bend pipe or rebar into the shape of a staple and then drive it through the mesh into the bank (see photo next page).

Rock and wire mattress made from prefabricated baskets.

Wire mesh over stone. Note "rebar staple" driven through mesh into the bank





Typical sand-cement bag revetment.

SACKS. Burlap sacks filled with soil or sand-cement mixtures have long been used for emergency work along levees and streambanks during floods. In recent years commercially manufactured sacks (burlap, paper, plastics, etc.) have been used to protect streambanks in areas where riprap of suitable size and quality is not available at a reasonable cost. Although most types of sacks are easily damaged and will eventually deteriorate, those sacks filled with sand-cement mixtures can provide long-term protection if the mixture has set up properly. Sand-cement sack revetment construction is not economically competitive in areas where good stone is available. However, if quality riprap must be transported over long distances, this type of sack revetment can often be placed on an eroding streambank at a lesser cost than riprap.

If a permanent revetment is to be constructed, the sacks should be filled with a mixture of 15 percent cement (minimum) and 85 percent dry sand (by weight). The filled sacks should be placed in horizontal rows like common house brick beginning at an elevation below any toe scour (alternatively, riprap can be placed at the toe to prevent undermining of the bank slope). The successive rows should be stepped back approximately 1/2-bag width to a height on the bank above which no protection is needed. The slope steepness of the completed revetment should be no more than 1 foot vertical for 1 foot horizontal. After the sacks have been placed on the bank, they can be hosed down for a quick set or the sand-cement mixture can be allowed to set up naturally through rainfall, seepage or condensation. If cement leaches through the sack material, a bond will form between the sacks and prevent free drainage. For this reason weepholes should be included in the revetment design. The installation of weepholes will allow drainage of groundwater from behind the revetment thus helping to prevent pressure buildup that could cause revetment failure.

BLOCKS. Precast cellular blocks can be manufactured using locally available sand, cement, and aggregate or can be obtained from commercial sources. Cellular blocks are cast with openings to provide for drainage and to allow vegetation to grow through the blocks thus permitting the root structure to strengthen the bank. Fabric or a gravel blanket can be used as a filter under the blocks if there is any danger that the bank soil will be eroded through the block openings by streamflow or seepage. If a filter is used, technical assistance should be obtained to properly match the filter with the soil. Although specialized equipment can be used to install large sections of blocks, hand placement is frequently used when mechanized apparatus is not available, access to the bank is limited, or costs need to be minimized. After the blocks have been placed, the revetment has sufficient flexibility to conform to minor changes in bank shape. Solid blocks should not be used because the bank may not be able to drain freely and failure could occur.

USED TIRES. Used tires can often be found in large quantities around car service centers and junk yards. Because uses for old tires are limited, most of these tires eventually end up in a scrap pile or buried in a landfill. During the past 15 years, landowners and local governments have reported successful use of old tires for streambank protection. Tires have been placed both as a mattress and stacked back against the bank. Both methods appear to have good potential as an economical approach to protect a streambank.

During construction of a tire mattress on an eroding bank, two precautions should be considered to ensure that the mattress will stay in place.

Commercially manufactured cellular concrete blocks.

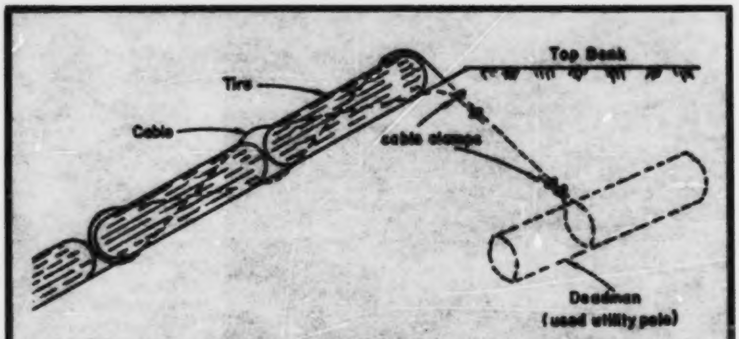
- The tires must be banded together; alternatively, cables running the length and width of the mattress can be woven through the tires.
- The top, toe, and the upstream and downstream ends of the mattress must be tied in to the bank (see diagram next page). If scour is anticipated, riprap should be placed at the toe of the mattress for additional protection.

While the precautions listed above are essential for successful construction of a stable mattress, other considerations can further improve the chances that the revetment will provide long-term bank protection.

- Holes can be cut, drilled, or burned in the tire sidewalls to prevent flotation.

LEFT: Used-tire mattress with tires banded together.

BELOW: Stacked-tire revetment.



Deadman and cable used to tie in top of mattress to bank. Piles, posts, or screw-type anchors are other types of materials that can be used as deadmen.

Stacked tires should be packed with stone or rubble.

- ☐ Presorting the tires by size may help to fit them together.
- ☐ Earth screw anchors (or some other type of anchor) fastened to the mattress can be placed in the bank at various points on the face of the revetment.
- ☐ The tires can be packed with stone or rubble.
- ☐ Willows can be planted inside the tires preferably at the beginning of the growing season. Once established the root system will further strengthen the bank and obscure the somewhat unsightly mattress. If willows are not readily available, another species should be planted. Assistance with species selection is discussed under vegetation.

If the mattress effectively controls the streambank erosion and remains intact, sediment may gradually cover the revetment. If willows have not been planted, volunteer vegetation will probably become established in areas with a temperate climate.

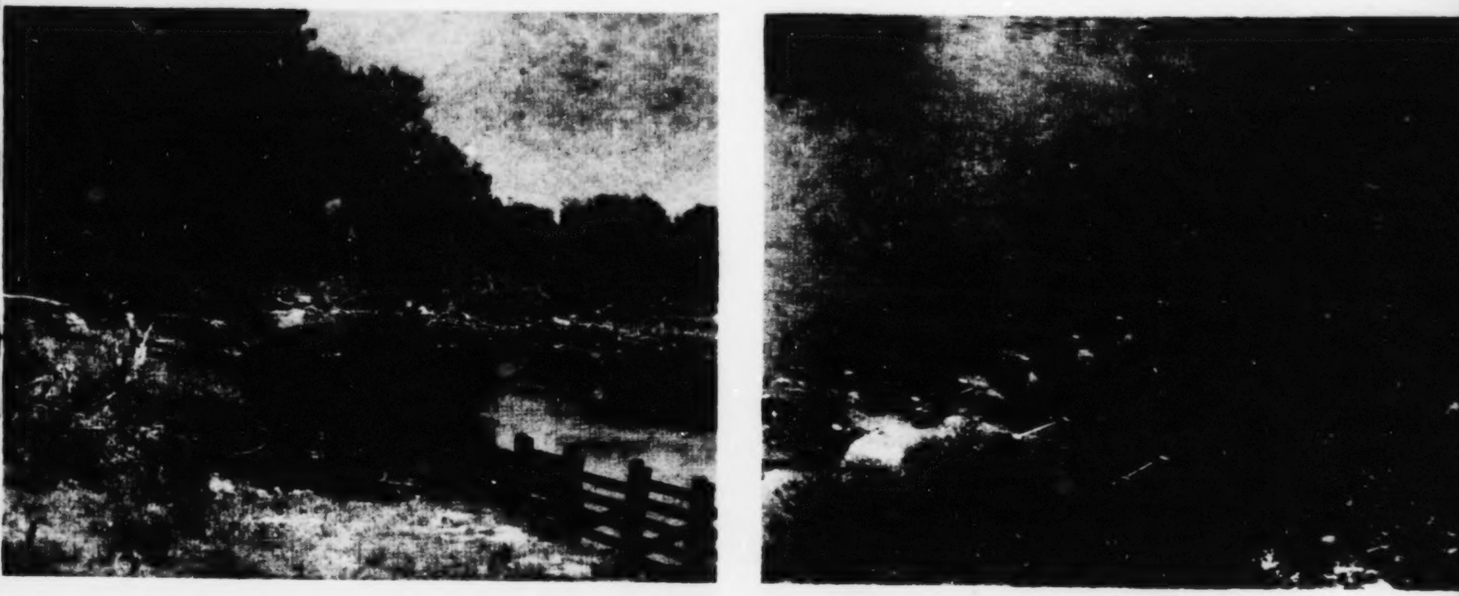
Prior to constructing a stacked-tire revetment, the bank face should be shaped so that the tires can be laid in horizontal rows. The revetment should be started at the toe of the bank and stepped back 6 to 12 inches per row. Each tire should overlap the two tires under it. The stacked tires should be packed tightly with stone or rubble. Any space behind the tires should be filled with free-draining soil so that the soil mass will not become saturated and cause the revetment to fail. In addition, the upstream and downstream ends of the revetment should be tied into the bank so that there is no flow behind the revetment.

FENCES. Fence construction parallel to a bankline can serve three purposes:

- ☐ To reduce the velocity of the stream near the bank so that erosion will be minimal.
- ☐ To encourage sediment deposition (as a result of the lower stream velocity) which will build up the bank.
- ☐ To develop a new bank alignment or to maintain the existing bank alignment; that is to keep the same channel shape along the eroding bankline so that additional land will not be lost.

Many types of local materials have been used for fence construction. Wood, used rails, pipe, steel beams, etc., are suitable as fence posts. The same materials can be used to back brace the fence. Wood and wire are generally used for the fencing material. If wire is used it should be strong enough to withstand the expected current load of water and debris. Field fencing and welded-wire fencing are effective against heavy and medium current loads, while chicken wire is suitable for lighter loads. Double row fences are sometimes constructed to provide additional resistance to stream attack with the gap between the fences filled with brush, hay, stone, or used tires.

Fences offer a good approach to landowners and local governments for protecting a streambank because no equipment is needed for construction other than machinery commonly found around farms or in



Wooden fence constructed along eroding streambanks. Note sediment deposition behind the fenceline and the tie-back fences between the fence and bank. If the fence is long, tie backs are needed to minimize flow between the fenceline and bank (left). Double row fence (right). Fences are most successful as a bank protection method on streams with heavy sediment loads.

local government maintenance barns; in addition, the materials needed to construct fences are widely available. A few important points should be considered during the design and construction of a fence:

a. If the stream carries extremely heavy debris during floods, the elevation of the fence top should be well below the high-water level so that debris such as heavy logs will pass over the fence.

b. The ends of the fence should be tied into the bank at the upstream and downstream ends of the fenceline to minimize flow between the fenceline and the bank that could cause erosion. If the fence is long, tiebacks are needed at regular intervals between the fenceline and bank.

c. Fencing should be fastened to the channel side of the fence post so that the force of the water and impact of debris will not be entirely on nails, staples, or bolts.

d. Wire fencing and hardware should be galvanized.

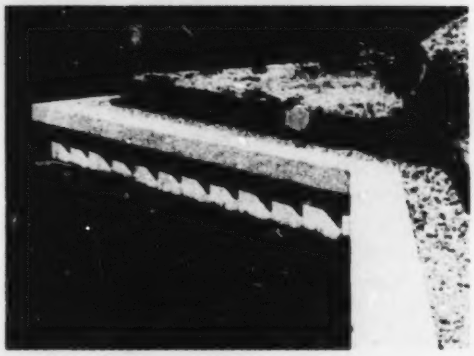
e. Fence posts should be placed to a depth equal to 1/2 to 2/3 of their total length. If stream velocities of 10 to 15 feet per second are expected during flood flow and the stream has a sandy bed, posts should be set to a depth of at least 15 feet (see footnote, page 38).

f. The toe of the fence must be protected with riprap or rubble if bed scour is anticipated, or if the fence is located on the cutbank of a bend.

KELLNER JACKS. A string of Kellner jacks can be placed along a bankline to prevent erosion in the same manner as a fence. Jacks can be assembled from angle iron, timber, pipe, rails, rebar, precast concrete, etc. Each jack consists of three members bolted or welded together at their midpoint such that each member is at right angles to the other two (similar to the shape of a toy jack). The members are then laced together with cable. Finally, the jacks are cabled together to form a string along the bankline. Additional strings can be placed perpendicular to the bankline to tie the main string in with the bank and to reduce the stream velocity against the bank.

Kellner jacks assembled from angle iron.

BULKHEADS. Bulkheads can be used to prevent streambank erosion or failure. As an additional benefit, a bulkhead may provide a substantial increase in waterfront area and an improvement in water/land access. Concrete, steel, timber, and more recently, aluminum, corrugated asbestos, and used tires have been used to construct bulkheads. Concrete and steel bulkheads generally cost at least four times as much as a comparable bulkhead of another material; however, the service life is longer and less maintenance is required. Timber and used tires are the most commonly available materials for economical bulkhead construction and have been used by many landowners and local governments to protect streambanks.



***ABOVE:* Timber bulkhead.**

***RIGHT:* Asbestos fiber bulkhead with a concrete cap serves as a boat dock and stabilizes the bank.**

***BELOW:* Used-tire bulkhead.**

Timber bulkhead construction is similar to common fence construction except that a few precautions should be observed:

- *a.* All wood should be treated with preservative to minimize deterioration due to repetitive wetting and drying or insect activity.
- *b.* The toe of the bulkhead should always be protected with riprap or rubble. The most common cause of bulkhead failure is scour around the pilings, followed by the structure tipping over due to the pressure of the bank behind the bulkhead.
- *c.* Piles should be anchored to deadmen buried in the bank.
- *d.* Fill material placed between the bulkhead and natural bank should be free draining so that the soil behind the bulkhead will not become saturated and push the structure over.
- *e.* If there are no cracks between the planks, weepholes should be drilled in the fence at regular intervals to allow the bank to drain. Filter fabric or gravel can be placed as a filter behind openings in the fence to prevent fine soils from leaching through. If a filter is used, technical assistance should be obtained to properly match the filter with the soil.
- *f.* The bulkhead should be tied into the bank at the upstream and downstream end of the structure to prevent flow behind the bulkhead.

If used tires are readily available, an economical bulkhead can be constructed provided the completed structure is less than 4 feet high. The tires should be laid out in horizontal rows with each tire being tightly packed with stone or rubble. Further, the tires should be stacked so that all tires overlap the two tires under them. Any space between the bulkhead and the natural bank should be filled with free-draining soil. In addition, the upstream and downstream ends of the bulkhead should be tied into the bank to prevent flow behind the structure. This type of bulkhead can provide protection against erosion by stream currents and wave attack, but no protection against bank failure unless the tires are banded together and anchored to deadmen buried in the bank. If the tires are properly banded together and anchored into the bank, the bulkhead can be constructed to heights greater than 4 feet.

DIKES. Dikes can protect a streambank in two ways:

- By reducing the stream velocity as the current passes through the dike so that sediment deposition occurs instead of erosion (permeable dike).
- By deflecting the current away from the bank (impermeable dike).

While a structure that reduces the stream velocity or diverts currents is called a dike in many areas, several other terms are also used to describe the same type of structure, such as groin, spur, jetty, deflector, etc.

A permeable dike is most effective on streams carrying heavy sediment loads. As sediment-laden flow moves through the dike the sediment will be deposited on the streambed and bank if there is a sufficient reduction in water velocity. Deposited soil particles will build up the eroded bank and possibly lead to volunteer vegetation growth. A series of permeable dikes placed along an eroding bank (often called a dike field) can be constructed using several approaches; among the most common are board and wire fences. Materials to construct fences are readily available; however, these materials should be chosen with care to withstand anticipated piling scour, debris impact, and stream currents.

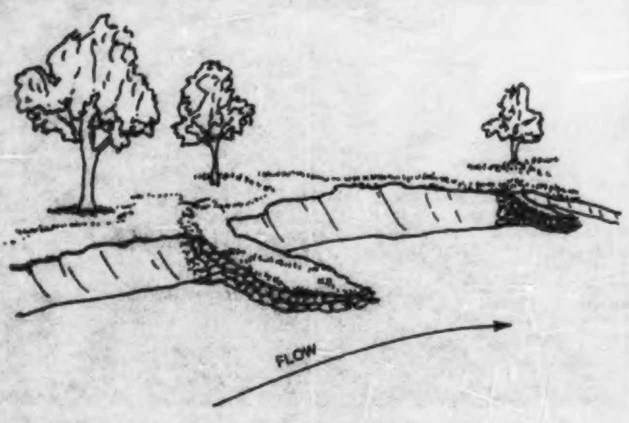
Although some types of impermeable dikes pass a small amount of flow, their major function is to divert eroding currents away from a bank. Impermeable dikes can be made from brush, logs, stone, or rubble. The first dike along an eroding bank should be constructed immediately upstream from the location on the bank where erosion is initially apparent. After this dike is completed, the current will be deflected toward

ABOVE: Board fence dike field.

LEFT: Brush dike.

LEFT: Brush dike tied into bank with cable.

BELOW: Wire fence dike field. Note that the top of each fence post is guyed to the bottom of the fence post immediately upstream and that each fence line is tied into the bank.



Impermeable dike constructed out of stone with earth fill.

the center of the channel and then may stay in midstream, return to the bank, or touch the opposite bank. The path of the current should be followed by throwing a float into the current upstream from the first dike. If the float does not return to the bank, one dike may be sufficient to arrest the erosion* (this procedure should be repeated to see if identical results are obtained). If the float does touch the bank on the same or opposite side, another dike should be constructed at the point of contact to deflect the current back toward midstream. The procedure should be continued until the float remains in midstream and does not touch either bank. The flow characteristics of the stream may change as the stream moves from a low water to flood condition, thus, the path of a float could change depending on the depth of the stream. Generally, dike locations should be determined when the stream is at a depth where the most erosion occurs. Professional guidance may need to be sought in order to determine the length, height, and geometry of a dike and its angle with respect to the streamflow.

Materials used to construct an impermeable dike ought to be heavy enough to stay in place and not be carried away by stream currents. If light materials must be used, such as brush, they should be well secured by weighting the material down and the dike should be tied into the bank with cable or chain.

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*Corps of Engineers experience has shown that one dike is usually not sufficient to eliminate a streambank protection problem; in fact, one dike usually causes more problems than it cures.

One Last Thought

...and now after carefully looking through this pamphlet the reader should be well prepared for his first attempt to protect a distressed bank...or at least understand why he cannot. Although the preceding pages have been filled with explanations, suggestions, and warnings the most important consideration is still that streambank protection is a complex subject. There are still more questions than answers. So what should the studious reader have gained from this pamphlet? Hopefully, he now understands that the chances of planning, building, and maintaining a project will be greatly improved by following a systematic plan of action as suggested in this pamphlet. Any less logical approach will not only compromise the resources of the builder, but the success of the project. Good luck!

Glossary

Abrasion. Removal of streambank soil as a result of sediment-laden water, ice, or debris rubbing against the bank.

Backwater area. The low-lying lands adjacent to a stream that become flooded during periods of high water.

Bar. A sand or gravel deposit found on the bed of a stream that is often exposed only during low-water periods.

Bed. The bottom of a channel.

Bend. A change in the direction of a stream channel.

Bed slope. The inclination of the channel bottom.

Blanket. Material placed on a streambank to cover eroding soil.

Caving. The collapse of a streambank by undercutting due to wearing away of the toe or an erodible soil layer above the toe.

Channel. A natural or man-made waterway that continuously or periodically passes water.

Check dam. A structure placed bank to bank downstream from a headcut.

Clay. Cohesive soil whose individual particles are not visible to the unaided human eye. Soil can be molded into a ball that will not crumble.

Cohesive soil. Microscopic soil particles that have natural resistance to being pulled apart at their point of contact.

Current. The flow of water through a stream channel.

Cut bank. The outside bank of a bend, often eroding and across the stream from a point bar.

Cut off. A channel cut across the neck of a bend.

Deadman. A log or block of concrete buried in a streambank that is used to tie in a revetment with cable or chain.

Dike (groin, spur, jetty, deflector). A structure designed (1) to reduce the water velocity as streamflow passes through the dike so that sediment deposition occurs instead of erosion (permeable dike) or (2) to deflect erosive currents away from the streambank (impermeable dike).

Discharge. The volume of water passing through a channel during a given time, usually measured in cubic feet per second.

Distressed streambank. A bank that has (or is) suffering erosion or failure.

Dredge material. Soil that is excavated from a stream channel.

Eddy current. A circular water movement that develops when the main flow becomes separated from the bank. The eddy current may then be set up between the main flow and the bank.

Erosion. In the general sense, the wearing away of the land by wind and water. As used in this pamphlet, the removal of soil particles from a bank slope primarily due to water action.

Failure. Collapse or slippage of a large mass of bank material into a stream.

Fill material. Soil that is placed at a specified location to bring the ground surface up to a desired elevation.

Filter. Layer of fabric, sand, gravel, or graded rock placed between the bank revetment or channel lining and soil for one or more of three purposes: to prevent the soil from moving through the revetment; to prevent the revetment from sinking into the soil; and to permit natural seepage from the streambank, thus preventing buildup of excessive groundwater pressure. If a filter is used by a landowner or local government, technical assistance should be obtained to properly match the filter with the soil.

Fine particles (or Fines). Silt and clay particles.

Flanking. Streamflow between a structure and the bank, possibly occurring because the structure was not properly tied into the bank.

Gravel. Soil particles ranging from 1/5 inch to 3 inches in diameter.

Greenbelt. Strip of trees and shrubs growing parallel to a stream that prevents overuse of the top bank area by man, animals, and machinery. This strip of vegetation also retards rainfall runoff down the bank slope and provides a root system which binds soil particles together.

Groundwater flow. Water that moves through the subsurface soil and rocks.

Groundwater table. The depth below the surface where the soil is saturated; that is the open spaces between the individual soil particles are filled with water. Above the groundwater table and below the ground surface the soil either has no water between the particles or is partially saturated.

Headcutting. The action of an upstream moving waterfall or locally steep channel bottom with rapidly flowing water through an otherwise placid stream. These conditions often indicate that a readjustment of a stream's discharge and sediment load characteristics is taking place.

Impermeable material. A soil that has properties which prevent movement of water through the material.

Infiltration. That portion of rainfall or surface runoff that moves downward into the subsurface rock and soil.

Launching. Process where stone stockpiled along top bank is undercut and slides downslope thus protecting the bank against future erosion.

Lower bank. That portion of the streambank below the elevation of the average water level of the stream.

Microscopic soil particles. Clay and silt; particles that cannot be observed by the unaided human eye.

Navigable streams. Waterways of sufficient depth and width to handle a specified traffic load.

Noncohesive soil. Soil particles that have no natural resistance to being pulled apart at their point of contact, for example, silt, sand, and gravel.

Overbank drainage. Water flow over top bank and down the slope.

Permit. Written authorization issued by the U.S. Army Corps of Engineers approving the construction of a streambank protection project.

Piping. Flow of groundwater through subsurface conduits in the bank.

Place. Synonym for construct; for example, to say that "a riprap revetment was placed on the streambank" is the same as saying "a riprap blanket was constructed on the streambank."

Point bar. The bank in a bend that has built up due to sediment deposition.

Project. As used in this pamphlet, the planning, construction, and maintenance of a revetment or river training works placed to protect a streambank.

Rapid drawdown. Lowering the elevation of water against a bank faster than the bank can drain leaving a pressure imbalance that may cause the bank to fail.

Reach. A section of a stream's length.

Revetment. A facing of stone, bags, blocks, pavement, etc., used to protect a bank against erosion.

Rill erosion. Removal of soil particles from a bank slope by surface runoff moving through relatively small channels.

River training works. Structures placed in a stream to direct the current into a predetermined channel.

Rock. Soil particles greater than 3 inches in diameter.

Rooted. Expression indicating that a bank has been excavated and the end of a structure (check dam, dike, etc.) has been placed in the cavity, thus retarding future streamflow around the end of the structure (flanking).

Sand. Soil particles ranging from 3/1000 inch to 1/5 inch in diameter; 3/1000 inch is the normal lower limit at which the unaided human eye can distinguish an individual particle.

Scour. The erosive action of flowing water in streams that removes and carries away material from the bed and banks.

Sediment. Soil particles that have been transported away from their natural location by wind or water action.

Sediment deposition. The accumulation of soil particles on the channel bed and banks.

Sediment load. The soil particles transported through a channel by streamflow.

Seepage. Groundwater emerging on the face of a streambank.

Shear. Force parallel to a surface as opposed to directly on the surface. An example of shear would be the tractive force that removes particles from a streambank as flow moves over the surface of the slope; on the other hand, a floating log that directly strikes the bank would not be a shear force.

Sheet erosion. The removal by surface runoff of a fairly uniform layer of soil from a bank slope.

Sill. See check dam.

Silt. Noncohesive soil whose individual particles are not visible to the unaided human eye. Soil will crumble when rolled into a ball.

Sloughing (or sloughing off). Movement of a mass of soil down a bank into the channel (also called slumping). Sloughing is similar to a landslide.

Streambank. The side slopes of a channel between which the streamflow is normally confined.

Streambank protection works. Structure(s) placed on or near a distressed streambank to control bank erosion or to prevent failure.

Streambed. See bed.

Streamflow. The movement of water through a channel.

Streambank erosion. Removal of soil particles from a bank slope primarily due to water action. Climatic conditions, ice and debris, chemical reactions, and changes in land and stream use may also lead to bank erosion.

Streambank failure. Collapse or slippage of a large mass of bank material into the channel.

Surface runoff. That portion of rainfall that moves over the ground toward a lower elevation and does not infiltrate the soil.

Texture. Refers to relative proportions of clay, silt, and sand in soil.

Tied in. An expression used to indicate that a revetment or dike is constructed to prevent or minimize streamflow between the structure and the bank.

Toe. The break in slope at the foot of a bank where the bank meets the bed.

Top bank. The break in slope between the bank and the surrounding terrain.

Tractive force. The drag on a streambank caused by passing water which tends to pull soil particles along with the streamflow.

Unravel. To lose material from the edges of a revetment.

Upper bank. That portion of the streambank above the elevation of the average water level of the stream.

Velocity (of water in a stream). The distance that water can travel in a given direction during an interval of time.

Waters of the United States. Includes all dry land and water-covered areas below the ordinary high water marks on navigable and nonnavigable streams.

Watershed. An area confined by drainage divides usually having only one streamflow outlet.

Wave attack. Impact of waves on a streambank.

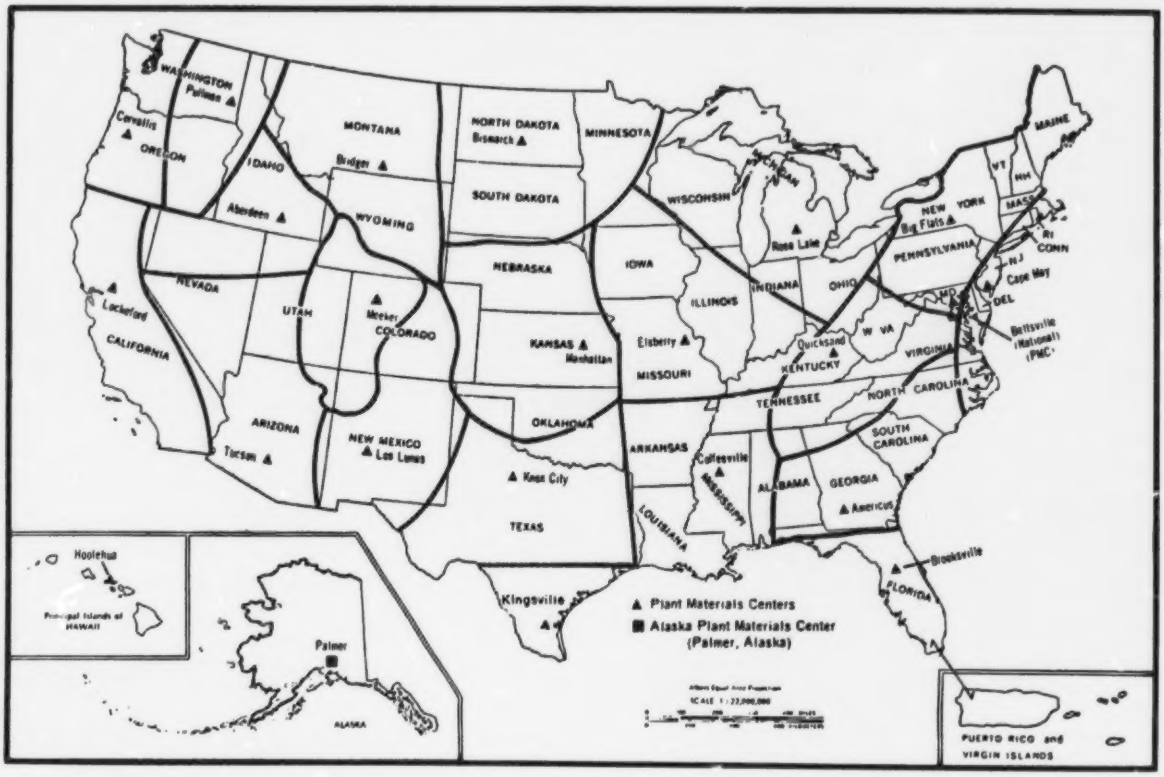
Weathering. Physical disintegration or chemical decomposition of rock due to wind, rain, heat, freezing, thawing, etc.

Weephole. Opening left in a revetment or bulkhead to allow groundwater drainage.

Soil Conservation Service
Plant Materials Centers

These Centers conduct studies to select or develop improved plants for erosion control and can provide information on the use of these plants for specific applications such as streambank protection.

Center	Address	Telephone
Alaska	Star Rt. B, Box 7440, Palmer, AK 99645 (Operated by the State of Alaska)	907 745-4469
Arizona	3241 Romero Road, Tucson, AZ 85705	602 629-6491
California	P.O. Box 68, Lockeford, CA 95237 (Open Tuesday - Friday)	209 727-5319
Colorado	P.O. Box 448, Meeker, CO 81641	303 878-5131
Florida	6225 U.S. 41 N., Brooksville, FL 33512	904 796-9600
Georgia	P.O. Box 688, Americus, GA 31709	912 924-2286
Hawaii	P.O. Box 236, Hoolehua, HI 96729	808 567-6378
Idaho	P.O. Box AA, Aberdeen, ID 83210	208 397-4181
Kansas	Rt. 2, Box 314, Manhattan, KS 66502	913 539-8761
Kentucky	Quicksand, KY 41363	606 666-5069
Maryland	National Plant Materials Center, Building 509, BARC-East, Beltsville, MD 20705	301 344-2175
Michigan	7472 Stoll Rd., East Lansing, MI 48823	517 641-6300
Mississippi	Rt. 3, Box 215A, Coffeeville, MS 38922	601 675-2588
Missouri	P.O. Box 108, Elsberry, MO 63343	314 898-2012
Montana	Rt. 1, Box 1189, Bridger, MT 59014	406 662-3579
New Jersey	Rt. 1, Box 236A, Cape May Court House, NJ 08201	609 465-5901
New Mexico	1036 Miller Street, S.W., Los Lunas, NM 87031	505 865-4684
New York	P.O. Box 395, Rt. 352, Big Flats, NY 14814	607 562-8404
North Dakota	P.O. Box 1458, Bismarck, ND 58502	701 223-8536
Oregon	3420 N.E. Granger Avenue, Corvallis, OR 97330	503 757-4812
Texas	South Texas Plant Materials Center, Caesar Kleherg Wildlife Research Institute, Texas A&I University, P.O. Box 218, Kingsville, TX 78363	512 595-2388
Texas	Rt. 1, Box 155, Knox City, TX 79529	817 658-3922
Washington	Rm. 257, Johnson Hall, WSU, Pullman, WA 99164-6428	509 335-7376


WASHINGTON
Pullman
Corvallis
OREGON
IDAHO
Aberdeen
MONTANA
Bridger
WYOMING
NORTH DAKOTA
Bismarck
SOUTH DAKOTA
MINNESOTA
WISCONSIN
MICHIGAN
Rose Lake
NEW YORK
Big Flats
VT
NH
MAINE
MASS
RI
CONN
PENNSYLVANIA
NJ
Cape May
DEL
MD
Beltsville (National) (PMC)
NEVADA
Lockeford
CALIFORNIA
UTAH
Meeker
COLORADO
NEBRASKA
IOWA
ILLINOIS
INDIANA
OHIO
W VA
VIRGINIA
KANSAS
Manhattan
Elsberry
MISSOURI
Quicksand
KENTUCKY
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
ARIZONA
Tucson
NEW MEXICO
Los Lunas
OKLAHOMA
ARKANSAS
Coffeeville
MISSISSIPPI
ALABAMA
GEORGIA
Americus
Knox City
TEXAS
LOUISIANA
Brooksville
FLORIDA
Kingsville
Hoolehua
Principal Islands of HAWAII
Palmer
ALASKA
Plant Materials Centers
Alaska Plant Materials Center (Palmer, Alaska)
SCALE 1:22,000,000
PUERTO RICO and VIRGIN ISLANDS

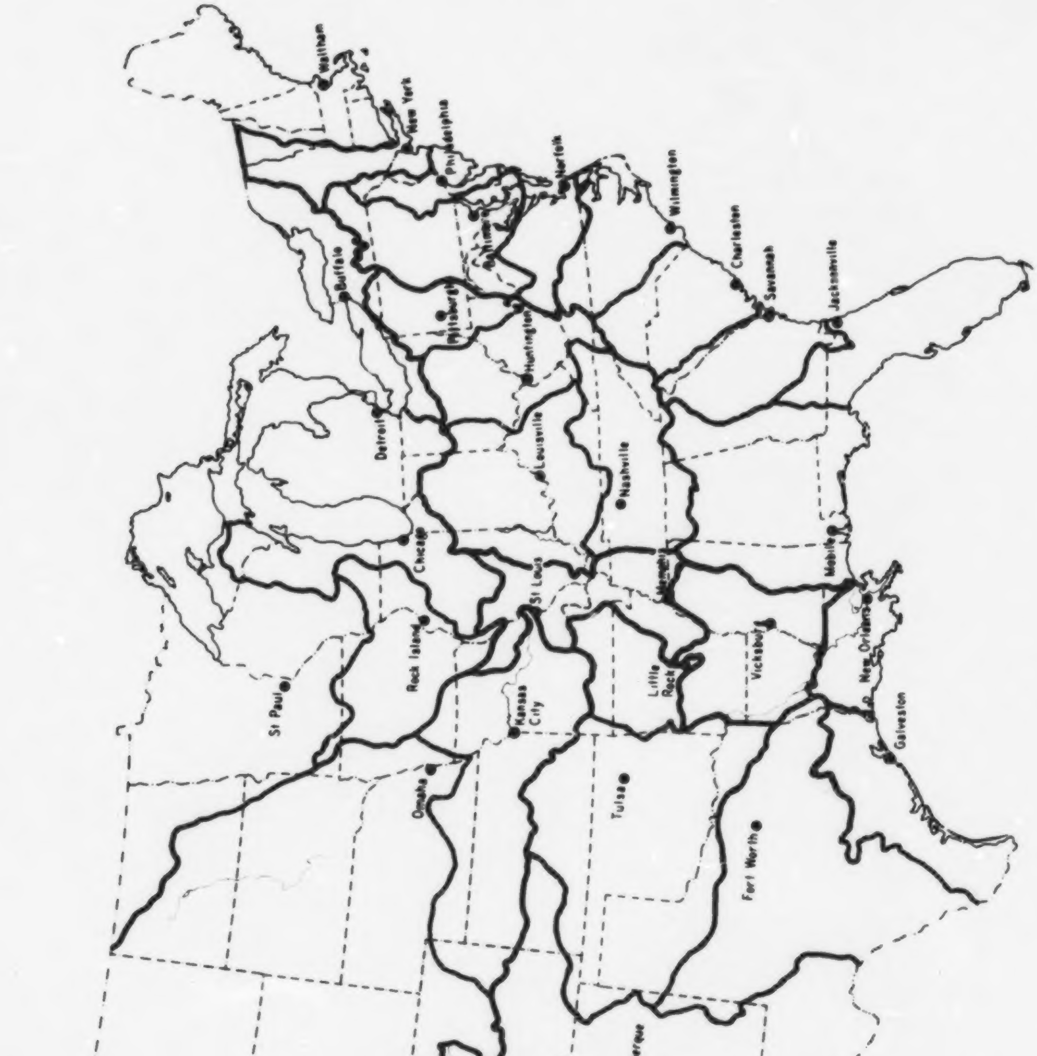
Location and service areas of SCS Plant Material Centers.

Corps of Engineers District Offices

These offices can help the landowner or local government with technical assistance and permit applications.

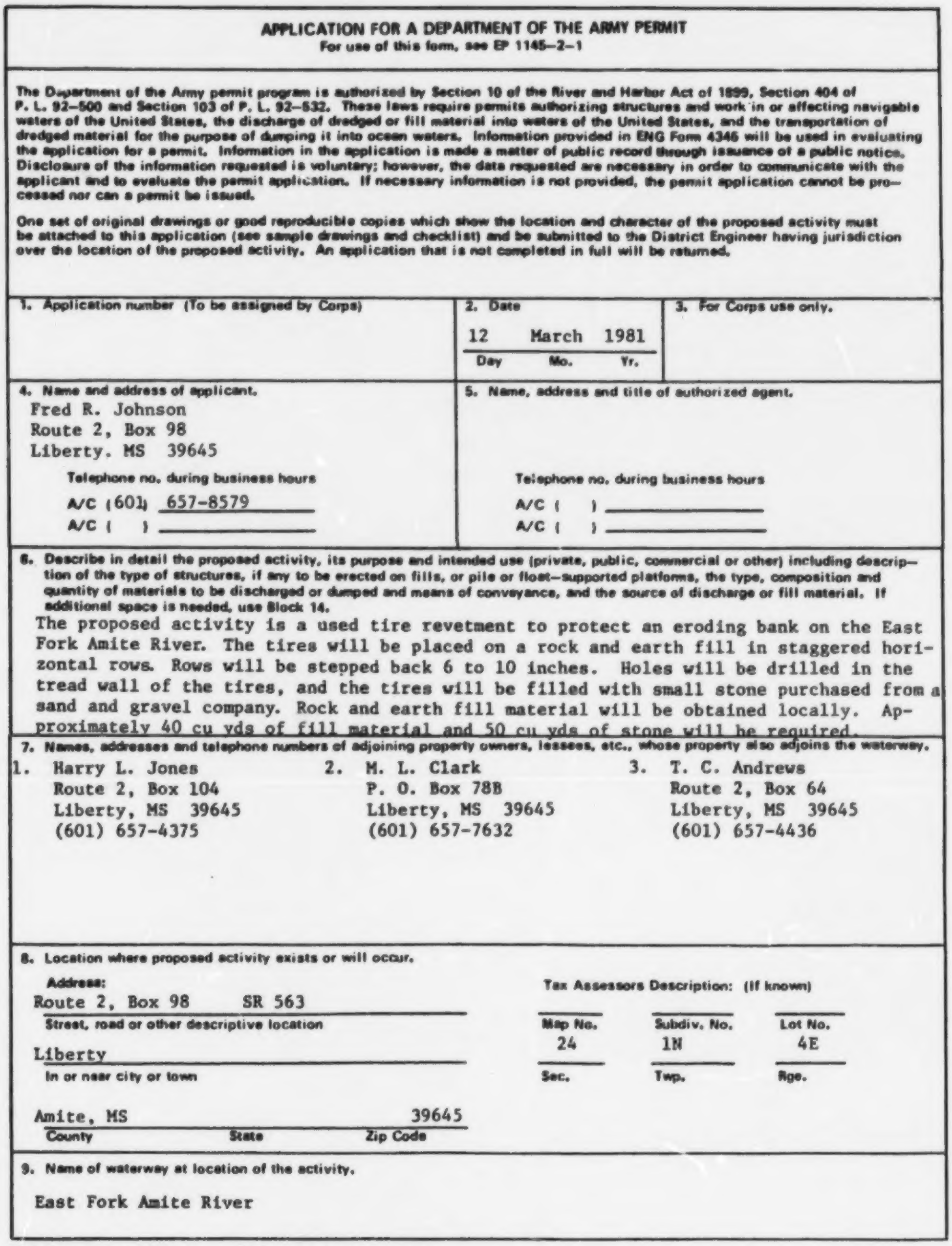
District	Address	Telephone
Alaska	Pouch 898, Anchorage, AK 99506	907 552-4144
Albuquerque	PO Box 1580, Albuquerque, NM 87103	505 766-2733
Baltimore	PO Box 1715, Baltimore, MD 21203	301 962-4616
Buffalo	1776 Niagara St., Buffalo, NY 14207	716 876-5454 Ext 2209
Charleston	PO Box 919, Charleston, SC 29402	803 724-4201
Chicago	219 S. Dearborn St., Chicago, IL 60604	312 353-6423
Detroit	PO Box 1027, Detroit, MI 48231	313 226-4680
Ft. Worth	PO Box 17300, Ft. Worth, TX 76102	817 334-2196
Galveston	PO Box 1229, Galveston, TX 77553	713 766-3005
Huntington	502 8th St., Huntington, WV 25721	304 529-5452
Honolulu	Bldg. 230, Ft. Shafter, Honolulu, HI 96858	808 438-9862
Jacksonville	PO Box 4970, Jacksonville, FL 32232	904 791-2235
Kansas City	700 Fed. Bldg., Kansas City, MO 64106	816 374-5241
Little Rock	PO Box 867, Little Rock, AR 72203	501 378-5551
Los Angeles	PO Box 2711, Los Angeles, CA 90053	213 688-5320
Louisville	PO Box 59, Louisville, KY 40201	502 582-5592
Memphis	B314 Clifford Davis Fed. Bldg., Memphis, TN 38103	901 521-3348
Mobile	PO Box 2288, 109 St. Joseph St., Mobile, AL 36628	205 690-2505
Nashville	PO Box 1070, Nashville, TN 37202	615-251-7161
New England	424 Trapelo Road, Waltham, MA 02254	617 647-8237
New Orleans	PO Box 60267, New Orleans, LA 70160	504 838-2201
New York	26 Fed. Plaza, Room 2109, New York, NY 10278	212 264-9113
Norfolk	803 Front St., Norfolk, VA 23510	804 441-3606
Omaha	6014 USPO & Courthouse, Omaha, NE 68102	402 221-3917
Philadelphia	US Custom House, 2nd & Chestnut St., Philadelphia, PA 19106	215 597-4802
Pittsburgh	1802 William S. Morehead Fed. Bldg., 1000 Liberty Ave., Pittsburgh, PA 15222	412 644-4130
Portland	PO Box 2946, Portland, OR 97208	503 221-6005

District	Address	Telephone
Rock Island	Clock Tower Bldg., Rock Island, IL 61201	309 788-6361 Ext 6274
Sacramento	650 Capitol Mall, Sacramento, CA 95814	916 440-2183, or 440-2292
St. Louis	210 Tucker Blvd., N., St. Louis, MO 63101	314 263-5662
St. Paul	1135 USPO & Custom House, St. Paul, MN 55101	612 725-7506
San Francisco	211 Main St., San Francisco, CA 94105	415 974-5630
Savannah	PO Box 889, 200 E. St. Julian St., Savannah, GA 31402	912 944-5279
Seattle	PO Box C-3755, Seattle, WA 98124	206 764-3750
Tulsa	PO Box 61, Tulsa, OK 74101	918 581-7396
Vicksburg	PO Box 60, Vicksburg, MS 39180	601 634-5012
Walla Walla	Bldg. 602, City-County Airport, Walla Walla, WA 99362	509 525-5500
Wilmington	PO Box 1890, Alton Lennon Fed. Bldg., Wilmington, NC 28402	919 343-4625


Waltham
New York
Philadelphia
Norfolk
Wilmington
Charleston
Savannah
Jacksonville
Buffalo
Baltimore
Pittsburgh
Huntington
Detroit
Louisville
Nashville
Chicago
St Louis
Memphis
Mobile
New Orleans
Vicksburg
Little Rock
Rock Island
St Paul
Kansas City
Omaha
Tulsa
Galveston
Fort Worth
Albuquerque
Walla Walla
Seattle
Portland
Sacramento
San Francisco
Los Angeles

Jurisdiction of Corps of Engineers Districts.

Engineer Form 4345 and Attachments



APPLICATION FOR A DEPARTMENT OF THE ARMY PERMIT
For use of this form, see EP 1145–2–1

The Department of the Army permit program is authorized by Section 10 of the River and Harbor Act of 1899, Section 404 of P. L. 92–500 and Section 103 of P. L. 92–532. These laws require permits authorizing structures and work in or affecting navigable waters of the United States, the discharge of dredged or fill material into waters of the United States, and the transportation of dredged material for the purpose of dumping it into ocean waters. Information provided in ENG Form 4345 will be used in evaluating the application for a permit. Information in the application is made a matter of public record through issuance of a public notice. Disclosure of the information requested is voluntary; however, the data requested are necessary in order to communicate with the applicant and to evaluate the permit application. If necessary information is not provided, the permit application cannot be processed nor can a permit be issued.

One set of original drawings or good reproducible copies which show the location and character of the proposed activity must be attached to this application (see sample drawings and checklist) and be submitted to the District Engineer having jurisdiction over the location of the proposed activity. An application that is not completed in full will be returned.

1. Application number (To be assigned by Corps)

2. Date
12 March 1981
Day Mo. Yr.

3. For Corps use only.

4. Name and address of applicant.
Fred R. Johnson
Route 2, Box 98
Liberty. MS 39645
Telephone no. during business hours
A/C (601) 657-8579
A/C ( ) ____________

5. Name, address and title of authorized agent.
Telephone no. during business hours
A/C ( ) ____________
A/C ( ) ____________

6. Describe in detail the proposed activity, its purpose and intended use (private, public, commercial or other) including description of the type of structures, if any to be erected on fills, or pile or float–supported platforms, the type, composition and quantity of materials to be discharged or dumped and means of conveyance, and the source of discharge or fill material. If additional space is needed, use Block 14.

The proposed activity is a used tire revetment to protect an eroding bank on the East Fork Amite River. The tires will be placed on a rock and earth fill in staggered horizontal rows. Rows will be stepped back 6 to 10 inches. Holes will be drilled in the tread wall of the tires, and the tires will be filled with small stone purchased from a sand and gravel company. Rock and earth fill material will be obtained locally. Approximately 40 cu yds of fill material and 50 cu yds of stone will be required.

7. Names, addresses and telephone numbers of adjoining property owners, lessees, etc., whose property also adjoins the waterway.

1. Harry L. Jones
Route 2, Box 104
Liberty, MS 39645
(601) 657-4375

2. M. L. Clark
P. O. Box 78B
Liberty, MS 39645
(601) 657-7632

3. T. C. Andrews
Route 2, Box 64
Liberty, MS 39645
(601) 657-4436

8. Location where proposed activity exists or will occur.

Address:
Route 2, Box 98 SR 563
Street, road or other descriptive location
Liberty
In or near city or town
Amite, MS 39645
County State Zip Code

Tax Assessors Description: (If known)

Map No.	Subdiv. No.	Lot No.
24	1N	4E
Sec.	Twp.	Rge.

9. Name of waterway at location of the activity.
East Fork Amite River

ENG Form 4345, 1 OCT 77 Edition of 1 Apr 74 is obsolete.

10. Date activity is proposed to commence. June 1981

Date activity is expected to be completed September 1981

11. Is any portion of the activity for which authorization is sought now complete? ☐ YES ☒ NO
If answer is "Yes" give reasons in the remark section. Month and year the activity was completed
________________. Indicate the existing work on the drawings.

12. List all approvals or certifications required by other federal, interstate, state or local agencies for any structures, construction, discharges, deposits or other activities described in this application.

Issuing Agency	Type Approval	Identification No.	Date of Application	Date of Approval
Mississippi Department of Natural Resources	Certification	--	12 March 1981	pending

13. Has any agency denied approval for the activity described herein or for any activity directly related to the activity described herein?

☐ Yes ☒ No (If "Yes" explain in remarks)

14. Remarks or additional information.

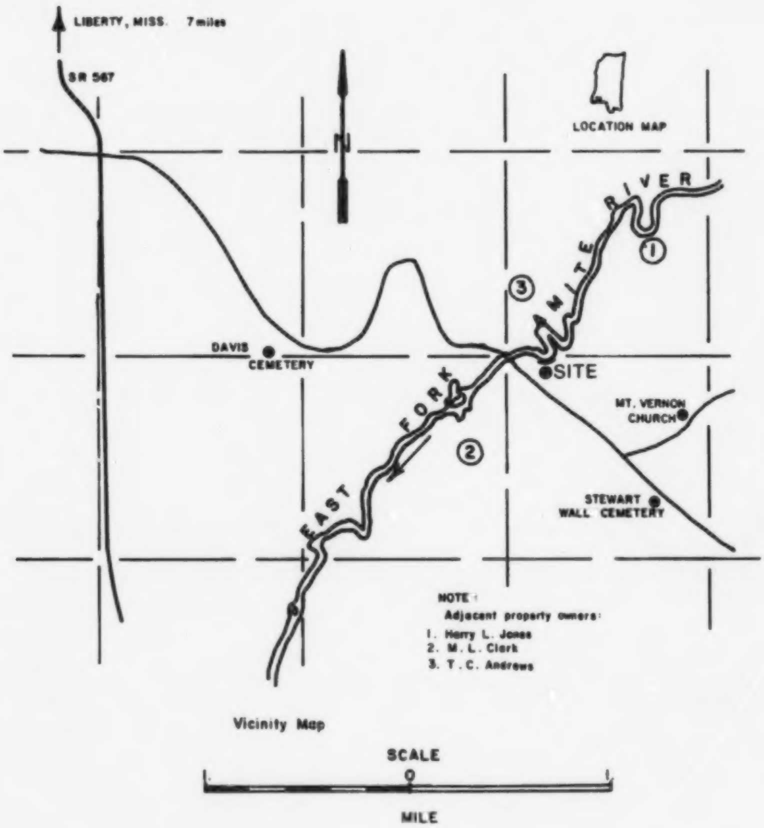
The streambank at this location is actively eroding at the rate of 3 feet per year, and the family home is now within 50 feet of the bank. The purpose of this project is to prevent further bank failure at this location.

15. Application is hereby made for a permit or permits to authorize the activities described herein. I certify that I am familiar with the information contained in this application, and that to the best of my knowledge and belief such information is true, complete, and accurate. I further certify that I possess the authority to undertake the proposed activities.

Fred R. Johnson
Signature of Applicant or Authorized Agent

The application must be signed by the applicant; however, it may be signed by a duly authorized agent (named in Item 5) if this form is accompanied by a statement by the applicant designating the agent and agreeing to furnish upon request, supplemental information in support of the application.

18 U. S. C. Section 1001 provides that: Whoever, in any manner within the jurisdiction of any department or agency of The United States knowingly and willfully falsifies, conceals, or covers up by any trick, scheme, or device a material fact or makes any false, fictitious or fraudulent statements or representations or makes or uses any false writing or document knowing same to contain any false fictitious or fraudulent statement or entry, shall be fined not more than $10,000 or imprisioned not more than five years, or both. Do not send a permit processing fee with this application. The appropriate fee will be assessed when a permit is issued.


LIBERTY, MISS. 7 miles
SR 567
N
LOCATION MAP
AMITE RIVER
EAST FORK
DAVIS CEMETERY
SITE
MT. VERNON CHURCH
STEWART WALL CEMETERY
①
②
③
SCALE
0
1
MILE

NOTE:
Adjacent property owners:
1. Harry L. Jones
2. M. L. Clark
3. T. C. Andrews

Vicinity Map

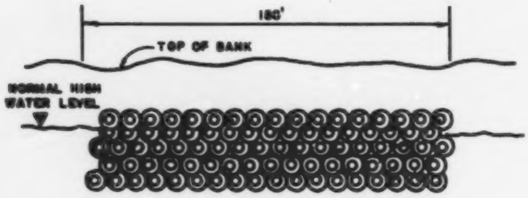
Proposed streambank protection on the East Fork Amite River near Liberty, in Amite County, State of Mississippi

Application by Fred Johnson

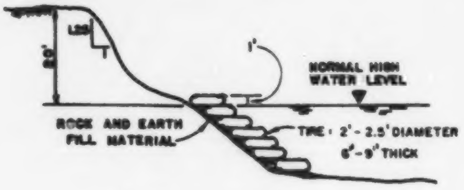
From: Mississippi State Highway Map

12 March 1981
Sheet 1 of 2

Two attachments to Engineer Form 4345; a map showing the location of the project and a drawing showing the important features of the proposed method to protect the streambank.


180'
TOP OF BANK
NORMAL HIGH WATER LEVEL

PLAN VIEW


1'
NORMAL HIGH WATER LEVEL
ROCK AND EARTH FILL MATERIAL
TIRE: 2'- 2.5' DIAMETER
6"-9" THICK

CROSS SECTION

Proposed streambank protection on the East Fork Amite River near Liberty, in Amite County, State of Mississippi

Application by Fred Johnson

Sheet 2 of 2